Well-to-Wheels analysis
of future automotive fuels and powertrains
in the European context

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WTW

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A joint study by

EUCAR / JRC / CONCAWE

Overview of Results

Outline

- Objectives
- What's new in this version
- Pathways
- WTT
  - Vehicle Assumptions
  - LPG
  - CNG
  - Start\stop
  - DPF
  - Hybrids
- WTW energy use and GHG emissions
  - Conventional liquid fuels
  - CNG, CBG
  - LPG
  - Conventional biofuels
  - Ethers
  - Synthetic fuels
  - Hydrogen
- Costs
- Potential for conventional fuel substitution and CO_2 avoidance
- Alternative uses of energy resources
- Conclusions

Study Objectives

- Establish, in a transparent and objective manner, a consensual well-to-wheels energy use and GHG emissions assessment of a wide range of automotive fuels and powertrains relevant to Europe in 2010 and beyond.
- Consider the viability of each fuel pathway and estimate the associated macro-economic costs.
- Have the outcome accepted as a reference by all relevant stakeholders.

  - ⇨ Focus on 2010+
  - ⇨ Marginal approach for energy supplies

- This slide pack gives an overview of the main changes and new features of the study compared to the December 2003 version
- It is intended for a technical audience already well versed in the subject matter
- For a full description of the study including assumptions, calculations and results, interested parties should consult the full set of reports and appendices available at http://ies.jrc.cec.eu.int/WTW

What's new in this version

- TTW
  - Reduced diesel DPF fuel penalty
  - LPG
  - Revised CNG engine data
  - Hybrids

- WTT
  - Revised pathways
    - CNG: methane losses during transport and range of transport energy consumption (pipeline pressure)
    - Ethanol from wheat (revised data and more options)
  - New pathways
    - Biogas
    - LPG
    - Ethanol from sugar cane and straw
    - FAEE (Fatty Acids Ethyl Ether)
    - Ethers
    - Waste wood via Black Liquor
    - CTL (Coal-To-Liquid)
    - CC&S (CO_2 Capture and Sequestration)
  - Entirely revised cost (incl. 2 crude oil price scenarios) and availability data

Well-to-Wheels Pathways

Resource

Crude oil

Coal

Natural Gas

Biomass

Wind

Nuclear

Fuels

Conventional Gasoline/Diesel/Naphtha

Synthetic Diesel

CNG (inc. biogas)

LPG

MTBE/ETBE

Hydrogen
(compressed / liquid)

Methanol

DME

Ethanol

Bio-diesel (inc. FAEE)

Powertrains

Spark Ignition*:*
Gasoline, LPG, CNG, Ethanol, H_2

Compression Ignition:
Diesel, DME, Bio-diesel

Fuel Cell

Hybrids: *SI, CI*, FC

Hybrid Fuel Cell + Reformer

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Tank-to-Wheels Matrix

Powertrains	PISI	DISI	DICI	Hybrid PISI	Hybrid DISI	Hybrid DICI	FC	Hybrid FC	Ref. + hyb. FC
Fuels									
Gasoline	2002 2010+	2002 2010+		2010+	2010+				2010+
Diesel fuel			2002 2010+			2010+			2010+
LPG	2002 2010+								
CNG Bi-Fuel	2002 2010+								
CNG (dedicated)	2002 2010+			2010+					
Diesel/Bio-diesel blend 95/5			2002 2010+			2010+			
Gasoline/Ethanol blend 95/5	2002 2010+	2002 2010+			2010+				
Bio-diesel			2002 2010+			2002 2010+			
MTBE/ETBE	2002 2010+	2002 2010+		2002 2010+	2002 2010+				
DME			2002 2010+			2010+			
Synthetic diesel fuel			2002 2010+			2010+			
Methanol									2010+
Naphtha									2010+
Compressed hydrogen	2010+			2010+			2010+	2010+	
Liquid hydrogen	2010+			2010+			2010+	2010+	

Vehicle Assumptions

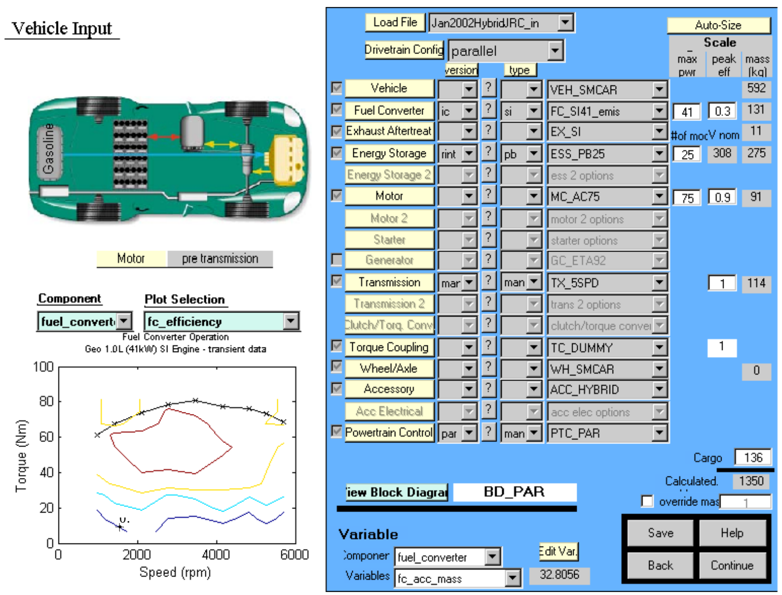
- Simulation of GHG emissions and energy use calculated for a model vehicle
  - Representing the European C-segment (4-seater Sedan)
  - Not fully representative of EU average fleet
  - New European Driving Cycle (NEDC)
- For each fuel, the vehicle platform was adapted to meet minimum performance criteria
  - Speed, acceleration, gradeability etc
  - Criteria reflect European customer expectations
- Compliance with Euro 3/4 was ensured for the 2002 / 2010 case
- No assumptions were made with respect to availability and market share of the vehicle technology options proposed for 2010+
- Heavy duty vehicles (truck and buses) not considered in this study

Vehicle Assumptions

Advisor Freeware Model

◎Vehicles simulations with **ADVISOR** Freeware
◎The entire vehicle + powertrain must be described

◎Data collection from manufacturers and others, helped by a data logger (sample below)



VEHICLE DEFINITION

Variable name	Type	Unit	ADVISOR name	FIAT Multipla
First coefficient of rolling resistance	Scalar	--	*veh_1st_rrc*	0.01
Second coefficient of rolling resistance	Scalar	s/m	*veh_2nd_rrc*	0.00
Coefficient of aerodynamic drag	Scalar	--	*veh_CD*	0.36
Vehicle frontal area	Scalar	m^2	*veh_FA*	2.60
Height of the vehicle center of gravity	Scalar	m	*veh_cg_height*	0.50
Fraction of total vehicle mass	Scalar	--	*veh_front_wt_fraction*	0.60
Distance between front and rear axle	Scalar	m	*veh_wheelbase*	2.67
Mass of the vehicle without components	Scalar	kg	*veh_glider_mass*	900
Test mass including fluids, passengers and cargo	Scalar	kg	*veh_mass*	unknown
Cargo mass	Scalar	kg	*veh_cargo_mass*	200

FUEL CONVERTER - CONVENTIONAL

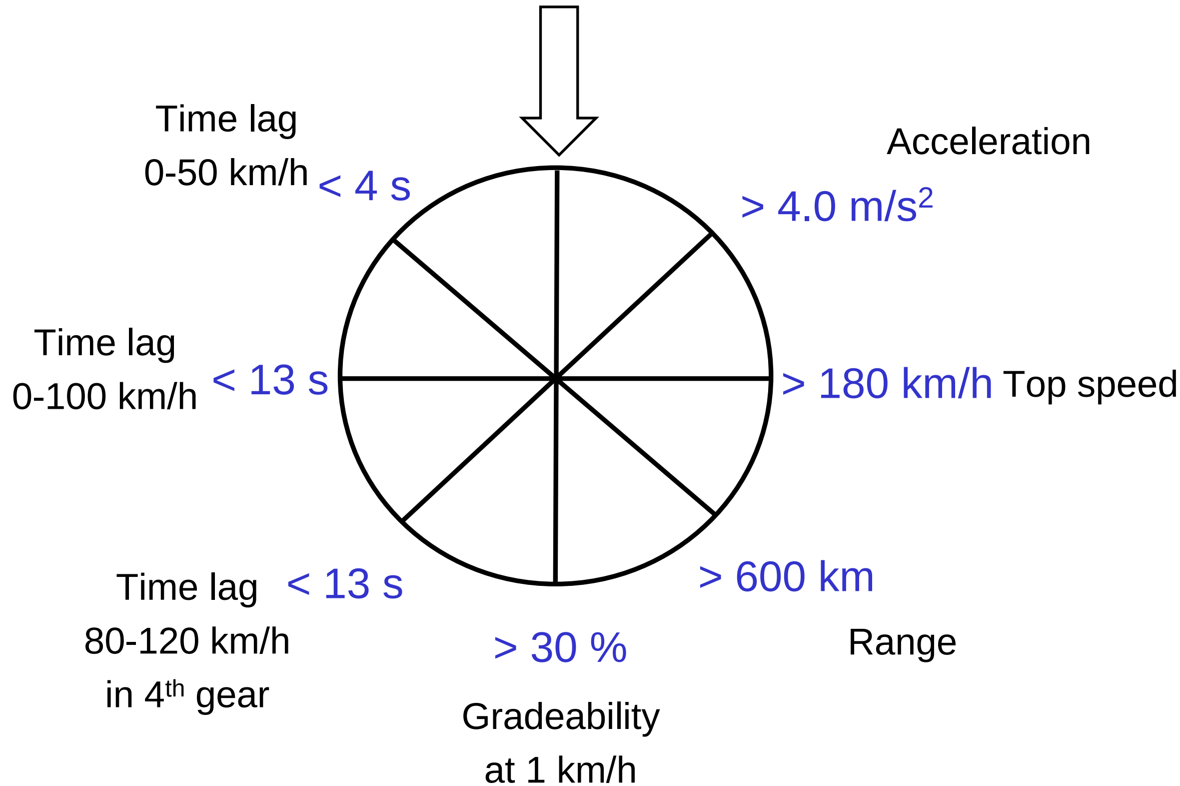
Variable name	Type	Unit	ADVISOR name	FIAT Multipla
Engine size (cylinder displacement)	Scalar	L	*fc_disp*	1.9
Vector of engine speed used to index other variables	Vector	rad/s	*fc_map_spd*	73-605
Vector of engine torque used to index other variables	Vector	N*m	*fc_map_trq*	0.0-144
Fuel use indexed by engine speed and torque	Matrix	g/s	*fc_fuel_map*	14-100
Engine out CO indexed by engine speed and torque	Matrix	g/s	*fc_co_map*	0-100
Engine out HC indexed by engine speed and torque	Matrix	g/s	*fc_hc_map*	0-100
Engine out NOx indexed by engine speed and torque	Matrix	g/s	*fc_nox_map*	0-100
Engine out PM indexed by engine speed and torque	Matrix	g/s	*fc_pm_map*	0-100
Fuel density	Scalar	g/L	*fc_fuel_den*	749
Lower heating value of the fuel	Scalar	J/g	*fc_fuel_lhv*	42600
Rotational inertia of the engine	Scalar	$kg{*}m^2$	*fc_inertia*	0.1
Maximum torque output indexed by engine speed	Vector	N*m	*fc_max_trq*	113-144
Fraction of waste heat that goes to exhaust	Scalar	--	*fc_ex_pwr_frac*	0.4
Engine coolant thermostat set temperature	Scalar	C	*fc_tstat*	96
Average heat capacity of engine	Scalar	J/kg/K	*fc_cp*	500
Average heat capacity of hood and engine	Scalar	J/kg/K	*fc_h_cp*	500
Surface area of hood and engine compartment	Scalar	m^2	*fc_hood_area*	1.5

Main OUTPUTS:
On the European Cycle (ECE-EUDC), the results concern:

- *MJ/km* necessary to perform the NEDC cycle
- GHG(g/km) in CO2 eq.emitted along the cycle

Common vehicle minimum performance criteria

- All technologies fulfil at least minimal customer performance criteria



- "Vehicle / Fuel" combinations comply with emissions regulations
  - The 2002 vehicles comply with Euro III
  - The 2010+ vehicles comply with Euro IV

LPG Characteristics

Composition	<= C2 : 3 %, C3 = 41 %, C4 = 55 % , >= C5 = 1%
LHV	46 MJ / kg
CO_2 emissions	3.02 kg CO_2 / kg
CO_2 emissions	65.7 kg CO_2 / GJ
Density	0.55 kg/l
% CH_4 in unburned HC	20%

(agreed with AEGPL)

Basic assumptions (favourable):

- Energy consumption map as for gasoline PISI
- Maximum torque curve as for gasoline (LPG liquid injection)

LPG Bi-fuel vehicle characteristics

		PISI	
		Gasoline	LPG bi-fuel
Powertrain			
Displacement	l	1.6	1.6
Powertrain	kW	77	77/77
Engine mass	kg	120	120
Gearbox mass	kg	50	50
Storage System			
Tank pressure	MPa	0.1	1
Tank net capacity	kg	31.5	14/16.5
Tank mass empty	kg	15	12/12
Tank mass increase including 90% fuel	kg	0	8
Vehicle			
Reference mass	kg	1181	1181
Vehicle mass	kg	1181	1189
Cycle test mass	kg	1250	1250
Performance mass	kg	1321	1329

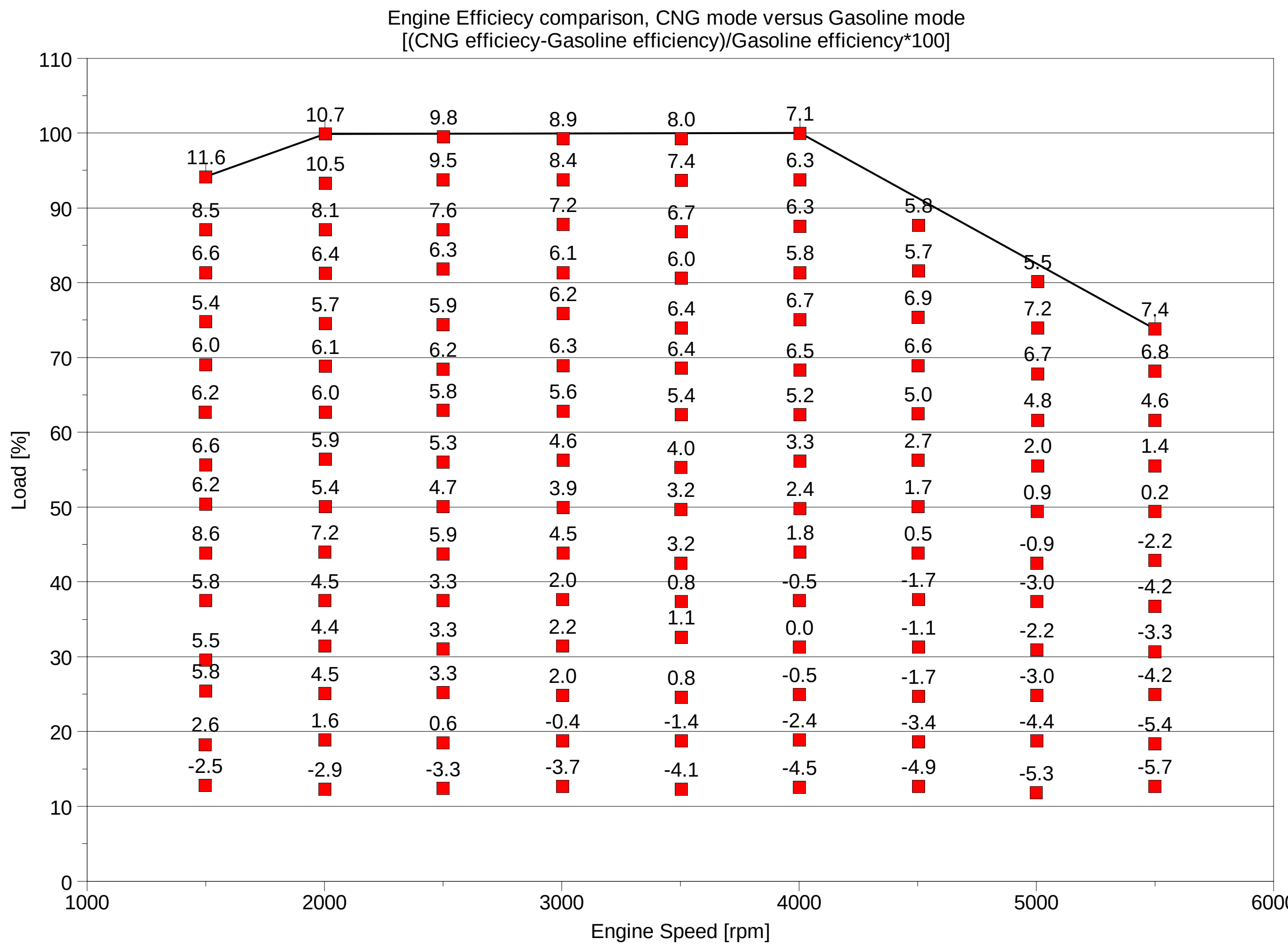
LPG vehicle results

	Fuel consumption (/100 km)			GHG emissions (g CO_2 eq/km)				Engine efficiency	Vehicle efficiency
	MJ	l	kg	as CO_2	as CH_4	as N_2O	Total	%	%
PISI conventional									
LPG 1.6 l	223.5	8.83	4.86	146.7	.8	0.9	148.4	18.7	16.6
Gasoline 1.6 l	223.5	6.95	5.21	166.2	.8	.9	167.9	18.7	16.6

- Same energy consumption
- 12 % lower TTW CO_2 emissions with LPG (C/H ratio)

CNG fuel consumption maps

New Data for the Bi-fuel CNG engine



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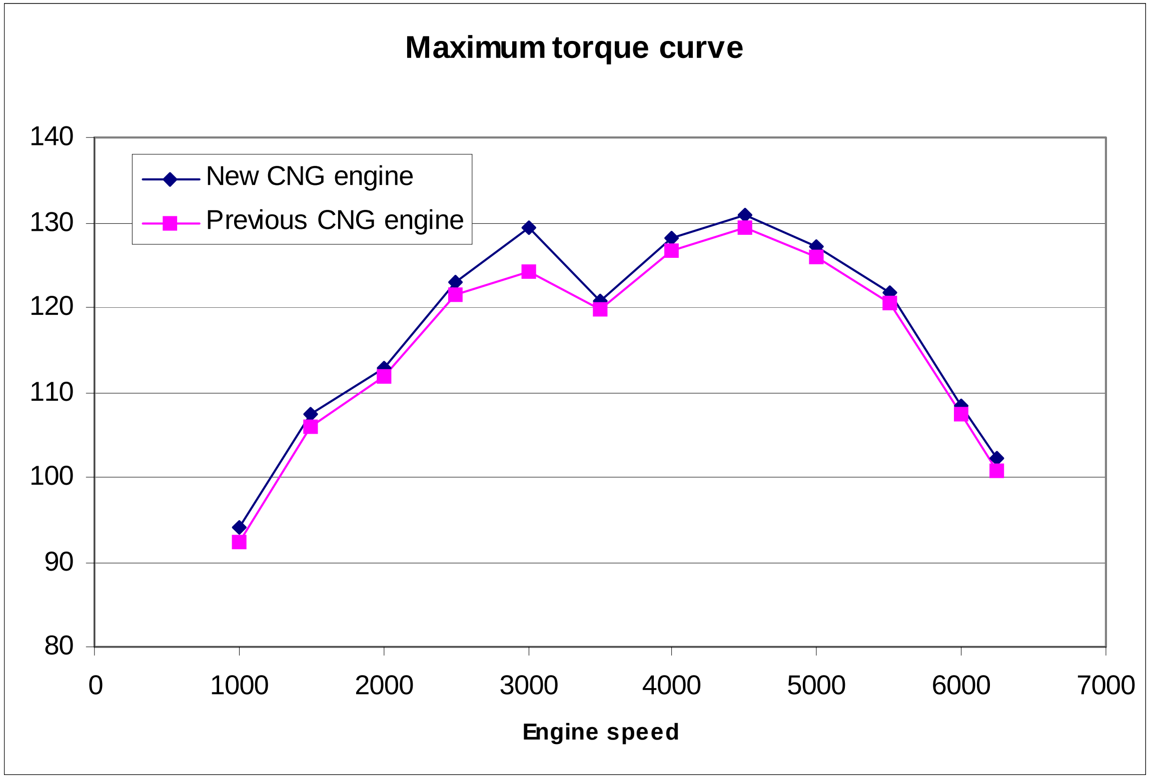
CNG fuel consumption maps

- CNG bi-fuel
  - Fuel consumption map calculated from
    - “% comparison” map (NG v. Gasoline, see previous slide)
    - Combined with the reference 1.6 l gasoline PISI map
  - The bi-fuel engine achieves slightly higher efficiency on CNG than on gasoline, because the ECU calibration can be adjusted to take advantage of the higher octane.

- CNG dedicated
  - fuel consumption map calculated
    - New efficiency map of the bi-fuel engine
    - Efficiency increased by 3 points v. bi-fuel version to account for higher compression ratio
  - For the dedicated engine, it is possible in addition to increase the compression ratio, giving a further efficiency improvement

CNG engine characteristics

- "New" maximum torque curve



- Final Outcome: dedicated CNG engine displacement can be reduced from 2.0 l (previous report) to 1.9 l

CNG vehicles characteristics

		PISI		
		Gasoline	CNG bi-fuel	CNG
Powertrain				
Displacement	l	1.6	1.6	1.9
Powertrain	kW	77	77/68	85
Engine mass	kg	120	120	150
Gearbox mass	kg	50	50	50
Storage System				
Tank pressure	MPa	0.1	25	25
Tank net capacity	kg	31.5	14/17.5	30
Tank mass empty	kg	15	12/61	103
Tank mass increase including 90% fuel	kg	0	59	87
Vehicle				
Reference mass	kg	1181	1181	1181
Vehicle mass	kg	1181	1240	1298
Cycle test mass	kg	1250	1360	1360
Performance mass	kg	1321	1380	1438

-14 kg compared to previous configuration

2002 CNG vehicle performance

		CNG PISI		*Target*
		Bi-fuel	Dedicated	
Time lag for 0-50 km/h	s	**4.5**	3.9	*<4*
Time lag for 0-100 km/h	s	**13.6**	11.8	*<13*
Time lag for 80-120 km/h in 4th gear	s	**13.8**	11.4	*<13*
Time lag for 80-120 km/h in 5th gear	s	18.6	15.1	-
Gradeability at 1 km/h	%	44	52	*>30*
Top speed	km/h	184	193	*>180*
Acceleration	m/s^2	**3.8**	4.4	*>4.0*

CNG Bi-fuel is still not meeting all performance criteria

	Fuel consumption (/100 km)			GHG emissions (g CO_2 eq/km)				Engine efficiency	Vehicle efficiency
	MJ	l (*)	kg	as CO_2	as CH4	as N2O	Total	%	%
PISI conventional									
1.6 CNG BiFuel	226.9	7.05	5.03	127.8	3.4	0.9	132.1	19.5	17.3
1.9 CNG dedicated	222.8	6.92	4.94	125.5	3.4	0.9	129.8	19.8	17.6
Gasoline 1.6 l	223.5	6.95	5.21	166.2	.8	.9	167.9	18.7	16.6

GHG TTW reductions (v. gasoline)

- CNG BF vehicle: - 21 % (performance criteria not met)
- CNG Dedicated: - 23 % (performance criteria met)

Stop & Start

- On the NEDC, fuel consumption during vehicle stop is calculated
- It represents 7.5 % of the total fuel consumption
- Remarks
  - Energy to restart the engine is not taken into account ↘
  - The slight modification in engine warm up is not taken into account ↘
- The maximum potential can't be fully retained for "real life" configurations
  - 3 % is a more realistic figure, Potentially applicable on all 2010 ICE configurations

Diesel particulate Filter (DPF)

- The Fuel Penalty induced by the DPF was reconsidered and decreased from 4% to 2.5 %

Hybrid optimisation

- As previously reported in the study, the hybrid technology, when applied to standard size power trains, has the potential to improve the fuel economy by around 15 %
- However, further improvements may be expected through additional optimisation of the power ratio between the thermal and electric motors
- A theoretical evaluation was carried out in the up-date in order to address this issue
- Objective: “adjust” the thermal engine/electric motor power ratio
  - To decrease fuel consumption and CO_2 emissions
  - While still meeting all standard performance criteria

Hybrid optimisation (cont'd)

- There is room for optimisation, in particular with regards to top speed

Previous Configuration (1,6 l)

		Gasoline PISI	*Target*
Time lag for 0-50 km/h	s	3.4	*<4*
Time lag for 0-100 km/h	s	9.9	*<13*
Time lag for 80-120 km/h in 4th gear	s	8.7	*<13*
Time lag for 80-120 km/h in 5th gear	s	10.5	-
Gradeability at 1 km/h	%	99	*>30*
Top speed	km/h	192	*>180*
Acceleration	m/s^2	4.8	*>4.0*

Hybrid optimisation (cont'd)

- 1st step: achieve 180 km/h as maximum speed
  - a 1,3 litre PISI ICE is enough!
- 2nd step: Check the other performance criteria (acceleration etc)
  - These were all met with a 1.28 l displacement (and still 14kW electric motor)

		Gasoline PISI	*Target*
Time lag for 0-50 km/h	s	3.7	*<4*
Time lag for 0-100 km/h	s	11.5	*<13*
Time lag for 80-120 km/h in 4th gear	s	10.8	*<13*
Time lag for 80-120 km/h in 5th gear	s	13.3	-
Gradeability at 1 km/h	%	77	*>30*
Top speed	km/h	180	*>180*
Acceleration	m/s^2	4.8	*>4.0*

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Characteristics of the "optimised" hybrid configuration

		Gasoline hybrid PISI	
		Original	Optimised
Powertrain			
Displacement	l	1.6	1.28
Power	kW	77	62
Engine weight	kg	120	100
Gearbox weight	kg	50	50
Storage System (liquid hydrogen)			
Tank net capacity	kg	22	22
Tank mass empty	kg	15	15
Tank mass increase including 90% fuel	kg	0	0
Electric parts			
Battery mass	kg	40	40
Power electric motor	kg	10	10
Torque coupler + …	kg	30	30
Vehicle			
Total Vehicle			
Reference mass	kg	1181	1181
Vehicle mass	kg	1261	1241
Cycle test mass	kg	1360	1360
Performance mass	kg	1401	1381

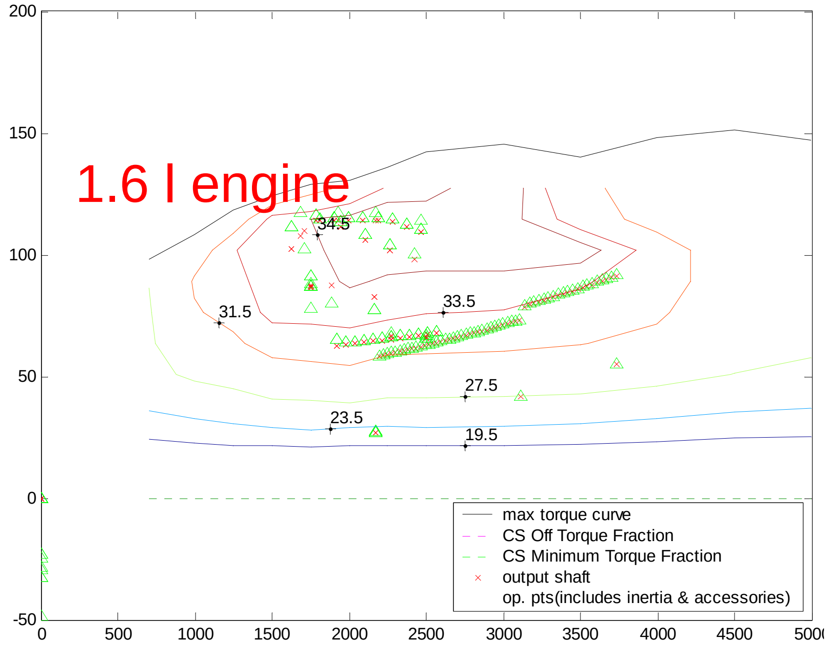
Results for the "optimised" hybrid configuration

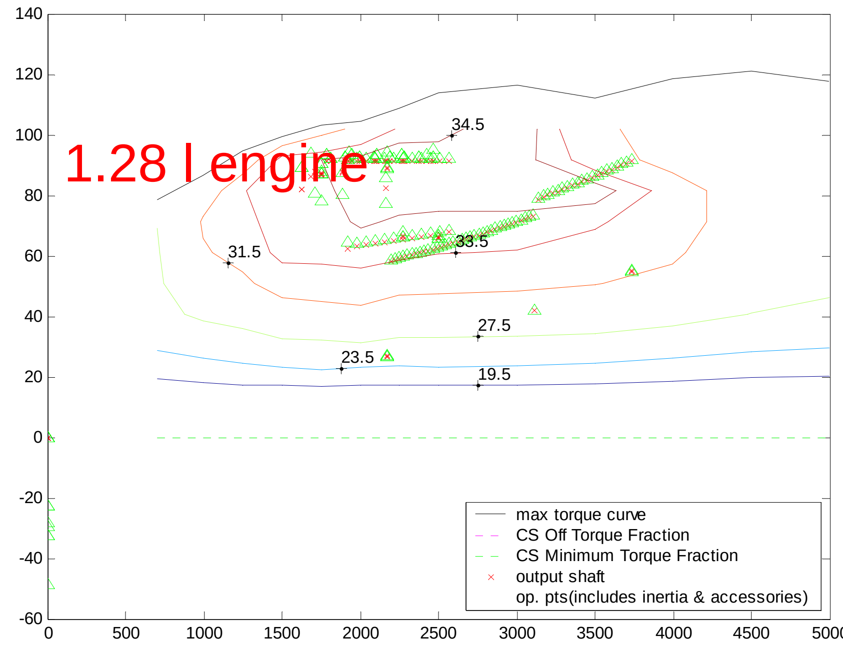
	Fuel consumption (/100 km)			GHG emissions (g CO2 eq/km)			
	MJ	l	kg	as CO_2	as CH4	as N2O	Total
PISI hybrid							
Gasoline 1.6 l	161.7	5.02	3.74	118.7	0.4	0.5	119.6
Gasoline 1.28 l	152.9	4.75	3.54	112.2	0.4	0.5	113.1

Fuel consumption and CO_2 emissions decrease by approximately 5%

Explanation

Thermal engine utilisation during the NEDC (hot start)





Better efficiency for the smaller engine

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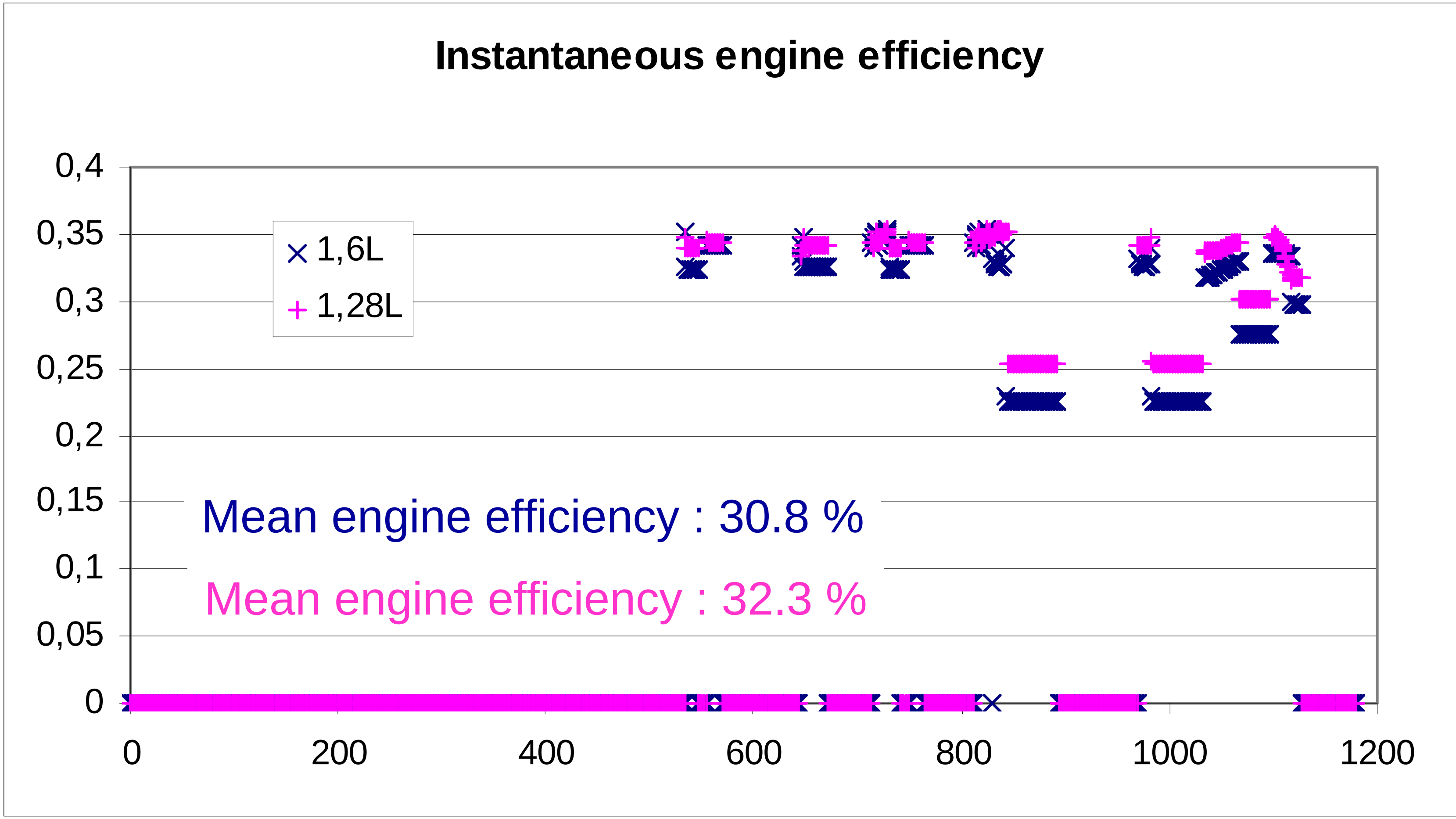
Hybrid efficiency during the NEDC (hot start)



5% improvement with respect to the mean thermal engine efficiency

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Hybrid configuration optimisation

- Thermal Engine / Displacement Optimisation:
  - 1,6 litre → 1,28 litre
  - Fuel consumption reduction: about 5 %
  - Fully complying with performance criteria

- Electric Motor / Power Optimisation:
  - 14 kW → 30 kW (still 1,28 l PISI ICE)
  - Fuel consumption reduction: 1 to 2 %
  - Fully complying with performance criteria

Hybrid configuration optimisation: outcome

- Theoretical hybrid power train simulations (thermal and electric motors) indicate that some 6% additional fuel economy improvement is potentially achievable from the basic 2010 hybrid PISI gasoline vehicle
- This additional potential 6% improvement is assumed to be applicable to all power trains and fuel types covered by the study
- This potential has been recognised by an increase of the variability range for hybrid fuel consumption

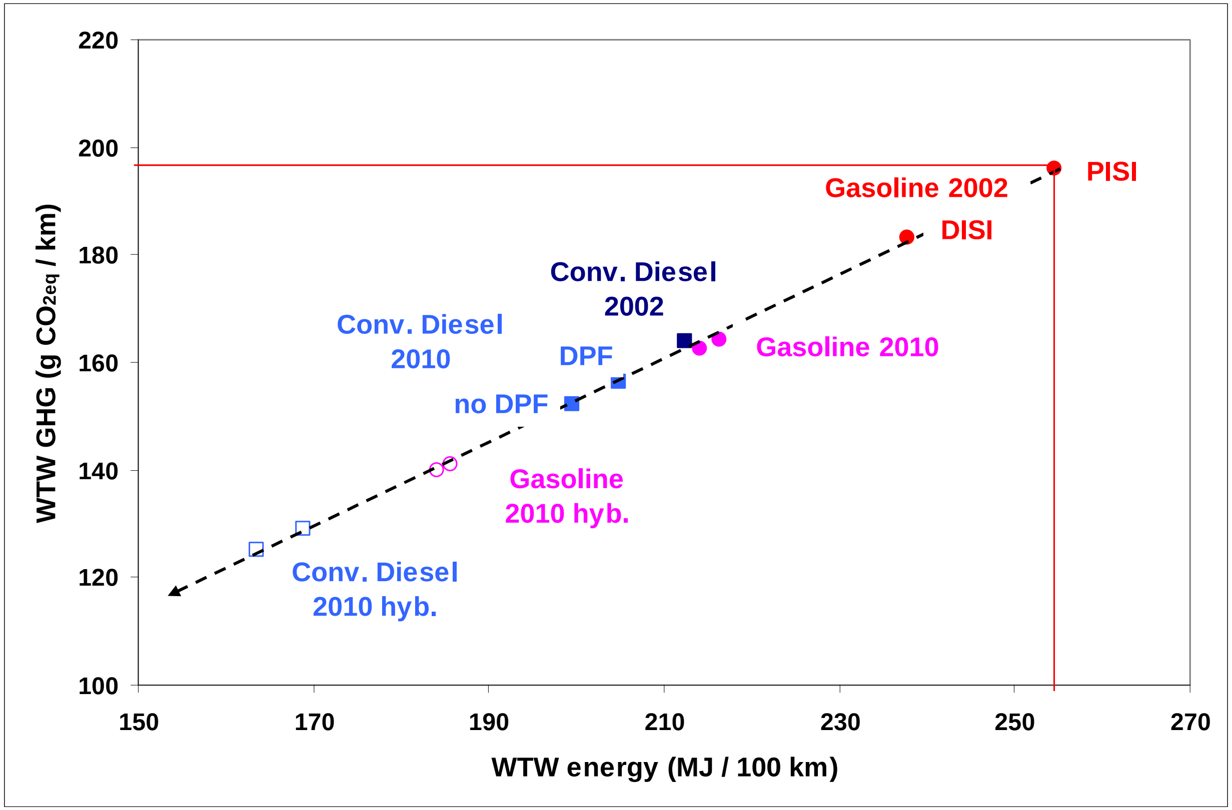
Well-to-Tank Matrix

Resource		Gasoline, Diesel, Naphtha (2010 quality)	CNG	LPG	Hydrogen (comp., liquid)	Synthetic diesel (Fischer-Tropsch)	DME	Ethanol	MT/ETBE	FAME/FAEE	Methanol	Electricity
Crude oil		X										
Coal					X(1)	X(1)	X				X	X
Natural gas	Piped		X		X(1)	X	X				X	X
	Remote		X(1)		X	X(1)	X(1)		X		X	X
LPG	Remote			X					X			
Biomass	Sugar beet							X	⇕			
	Wheat							X	X			
	Wheat straw							X				
	Sugar cane							X				
	Rapeseed									X		
	Sunflower									X		
	Woody waste				X	X	X	X			X	
	Farmed wood				X	X	X	X			X	X
	Organic waste		X(2)									X
	Black liquor				X	X	X				X	X
Wind												X
Nuclear												X
Electricity					X							

(1) with/without CO_2 capture and sequestration

(2) Biogas

Conventional Fuels from Crude Oil



- Continued developments in engine and vehicle technologies will reduce energy use and GHG emissions
  - Spark ignition engines have more potential for improvement than diesel
  - Hybridization can provide further GHG and energy use benefits

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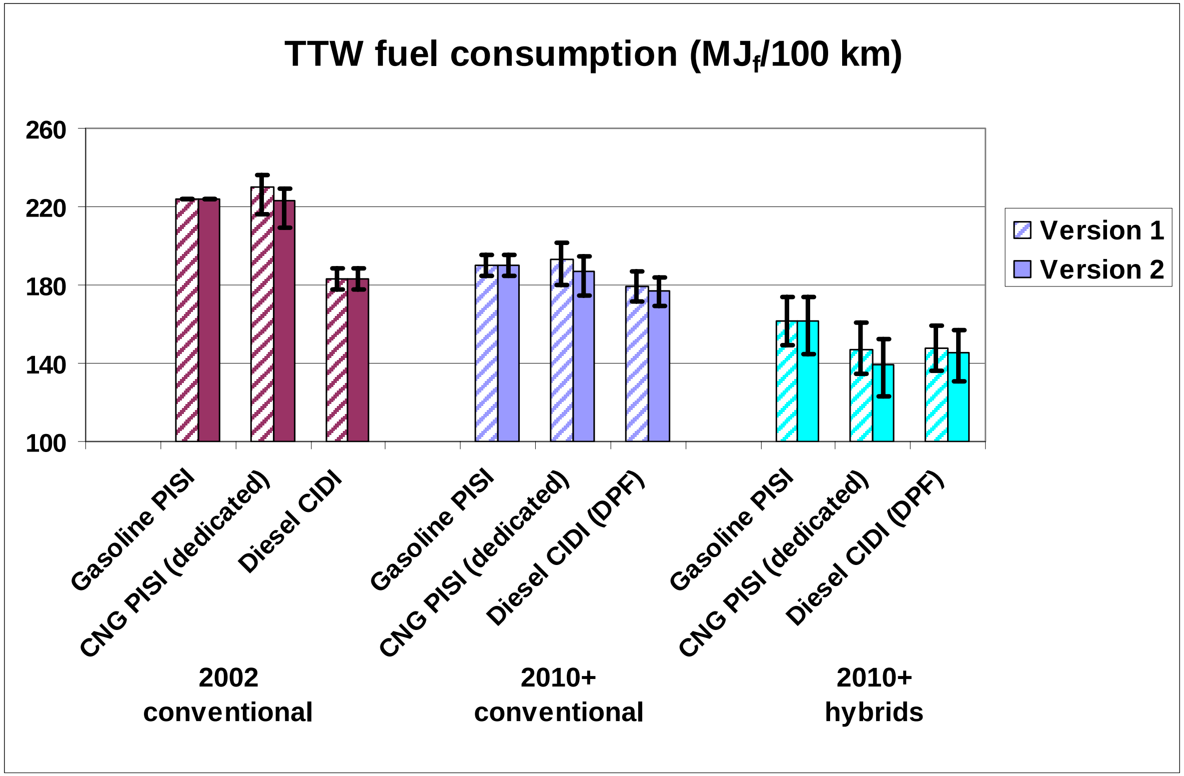
Compressed Natural Gas (CNG): vehicle technologies



- **CNG engines are currently slightly less efficient than gasoline engines**
- **In the future, the improvements on spark ignition engines will bring CNG close to diesel**
- **Hybridisation is particularly favourable for CNG**

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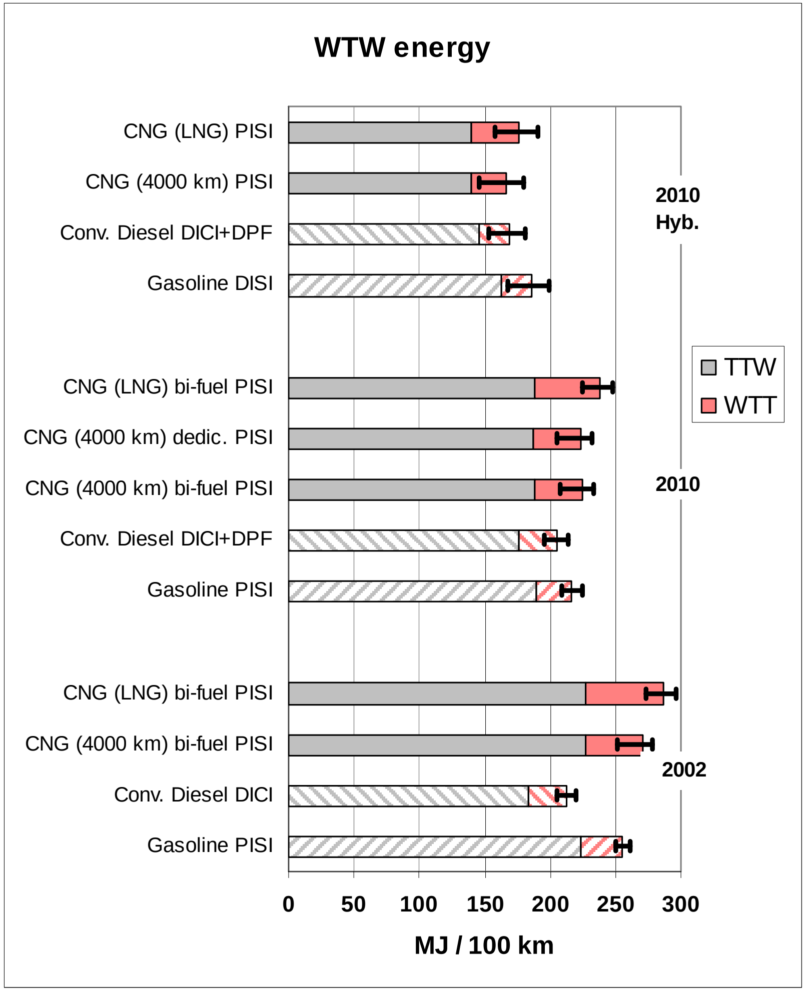
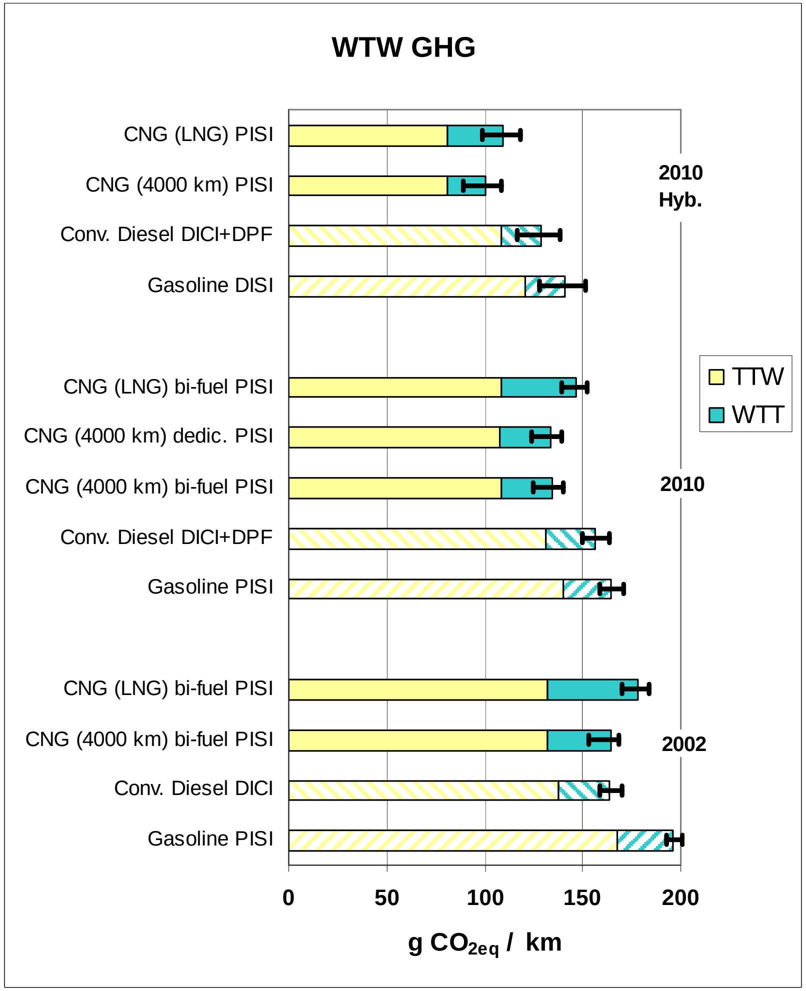
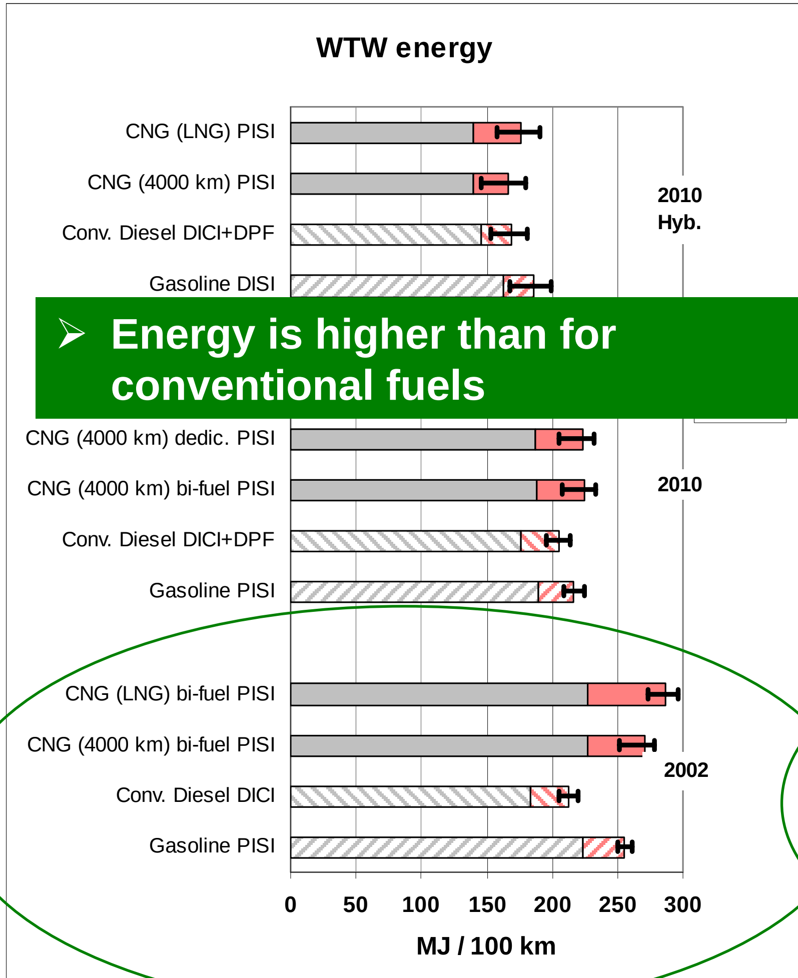
Compressed Natural Gas (CNG)

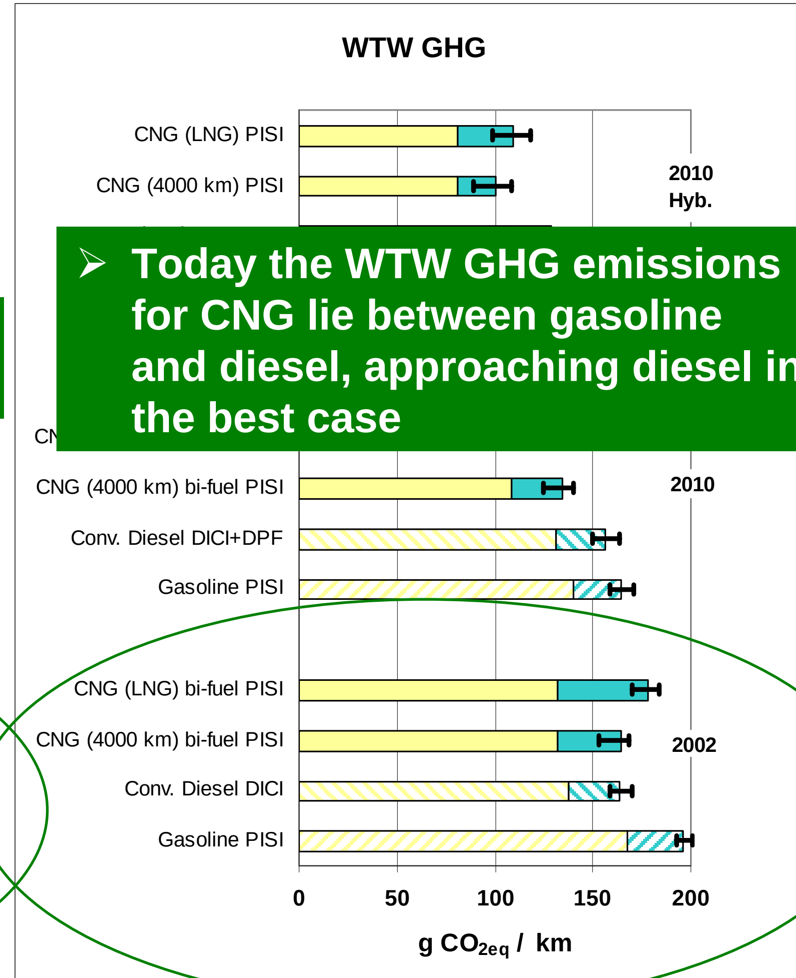




Compressed Natural Gas (CNG)



- Energy is higher than for conventional fuels



- Today the WTW GHG emissions for CNG lie between gasoline and diesel, approaching diesel in the best case

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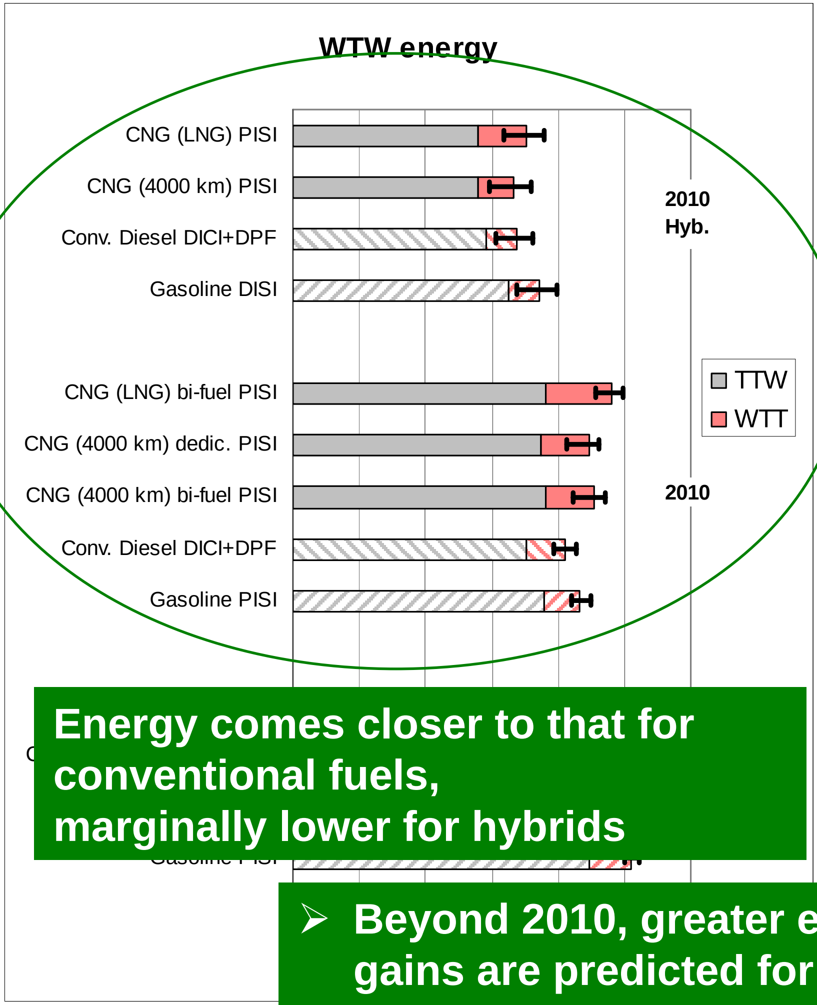
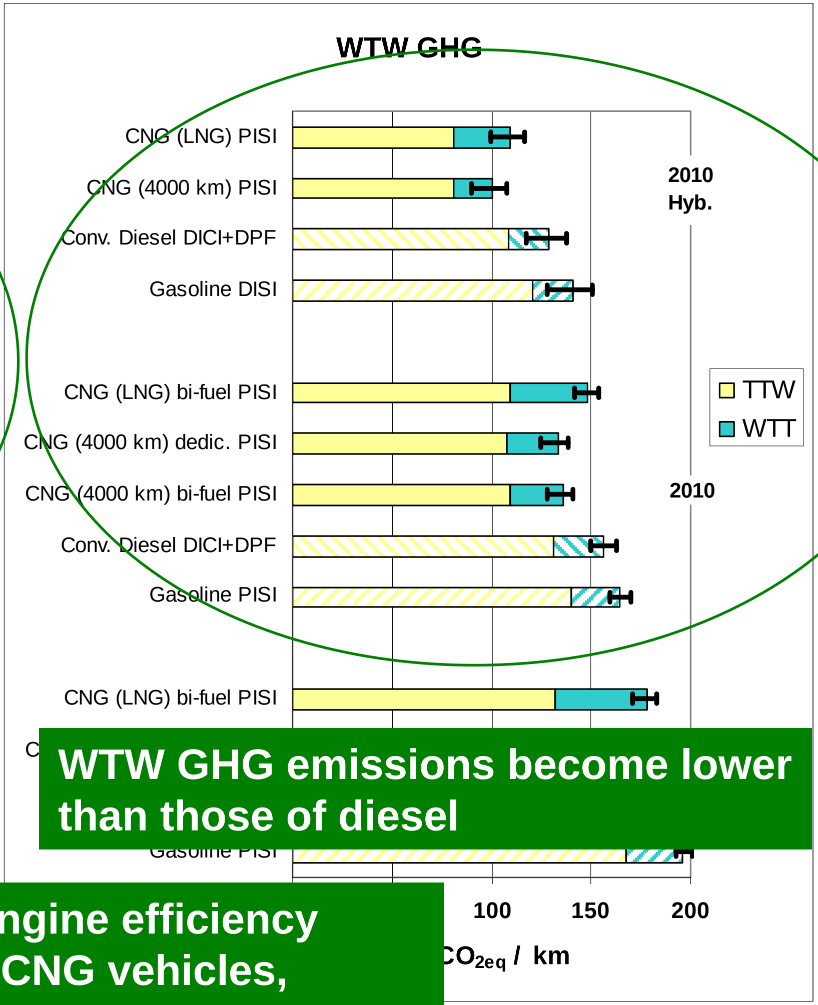
Compressed Natural Gas (CNG)



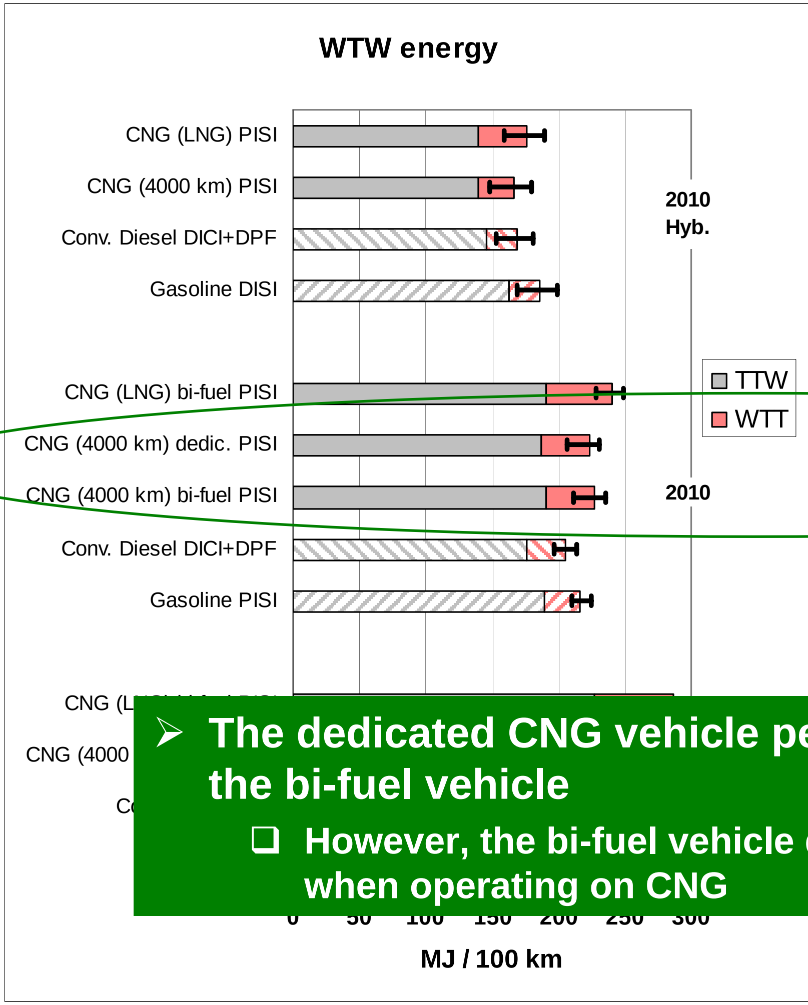


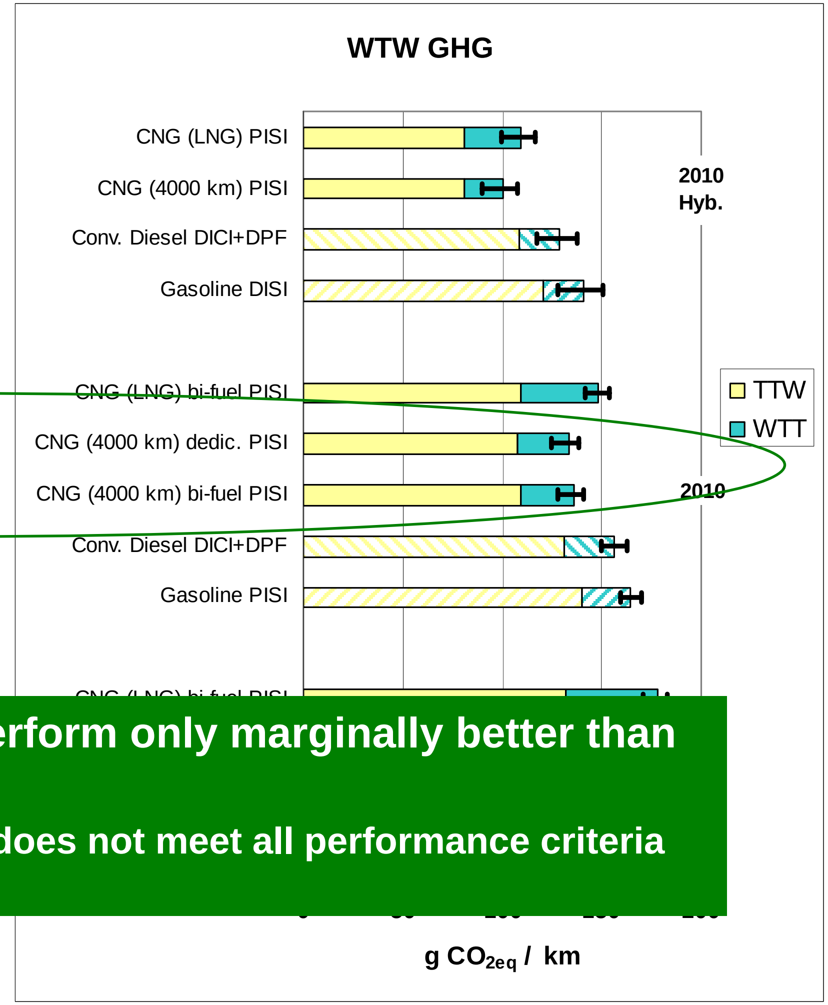
Energy comes closer to that for conventional fuels, marginally lower for hybrids

WTW GHG emissions become lower than those of diesel

- **Beyond 2010, greater engine efficiency gains are predicted for CNG vehicles, especially noticeable with hybridization**

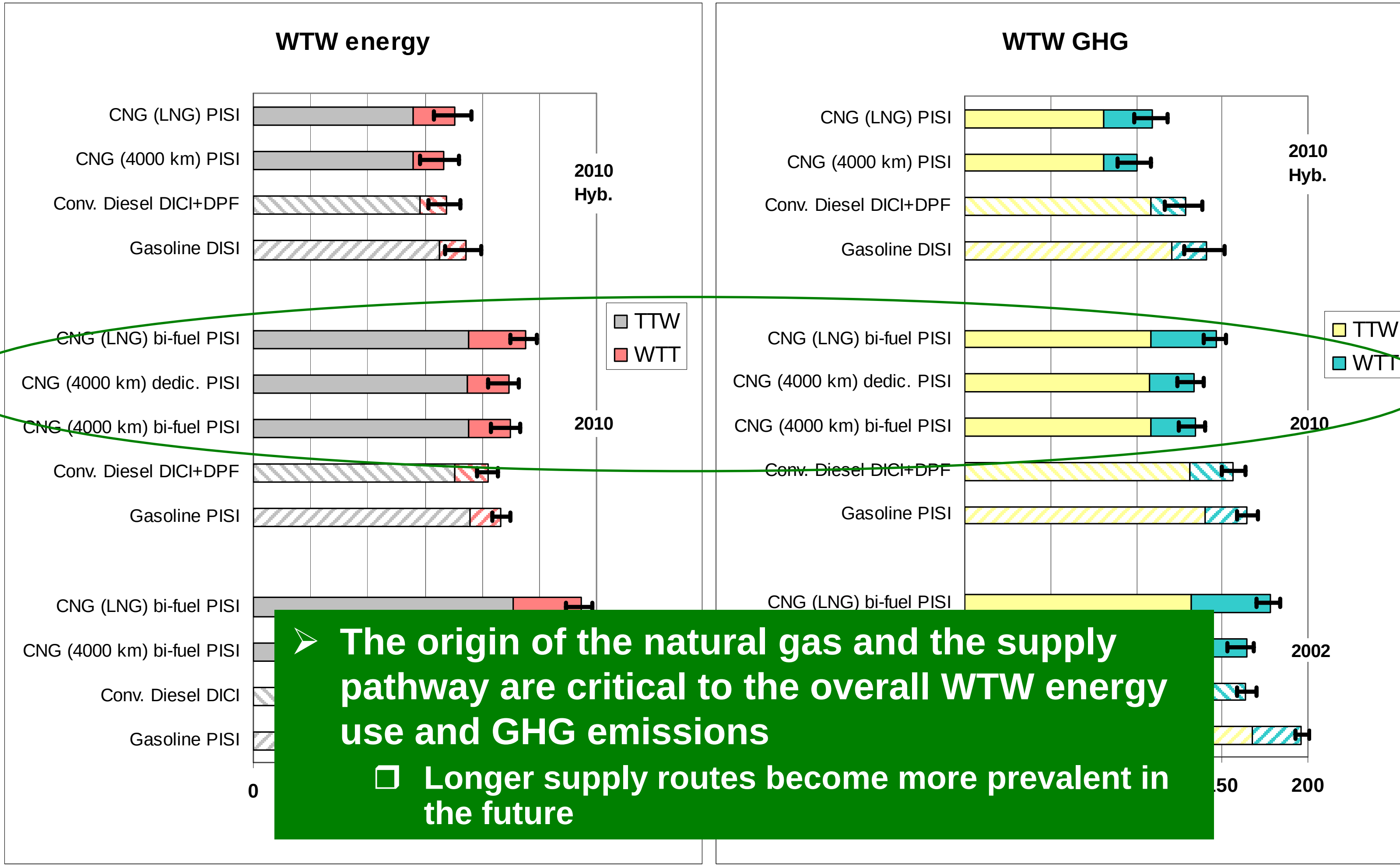
Compressed Natural Gas (CNG)





- **The dedicated CNG vehicle perform only marginally better than the bi-fuel vehicle**
  - **However, the bi-fuel vehicle does not meet all performance criteria when operating on CNG**

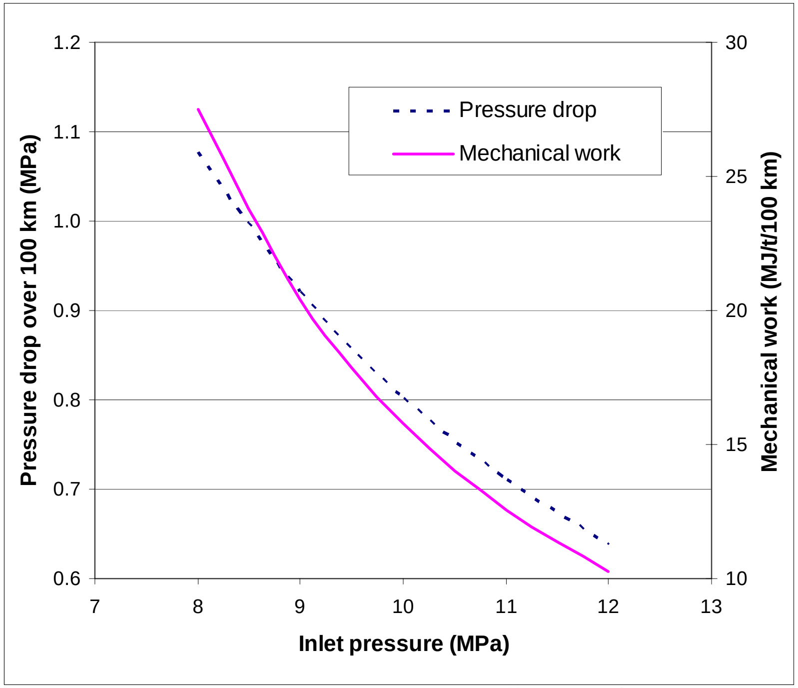
Compressed Natural Gas (CNG)

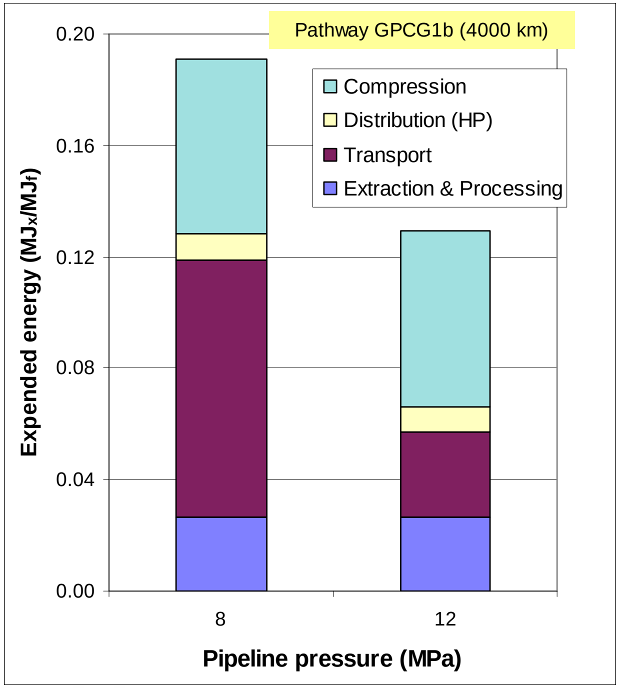


- **The origin of the natural gas and the supply pathway are critical to the overall WTW energy use and GHG emissions**
  - **Longer supply routes become more prevalent in the future**

Compressed Natural Gas (CNG)

- The origin of the natural gas and the supply pathway are critical to the overall WTW energy use and GHG emissions
  - Energy to transport NG through pipelines may decrease because of higher pressure pipelines
    - Our base case assumes 8 MPa, error bars include 12 MPa case
    - Future new lines may operate at up to 15 MPa
    - Global impact will be limited because of existing infrastructure





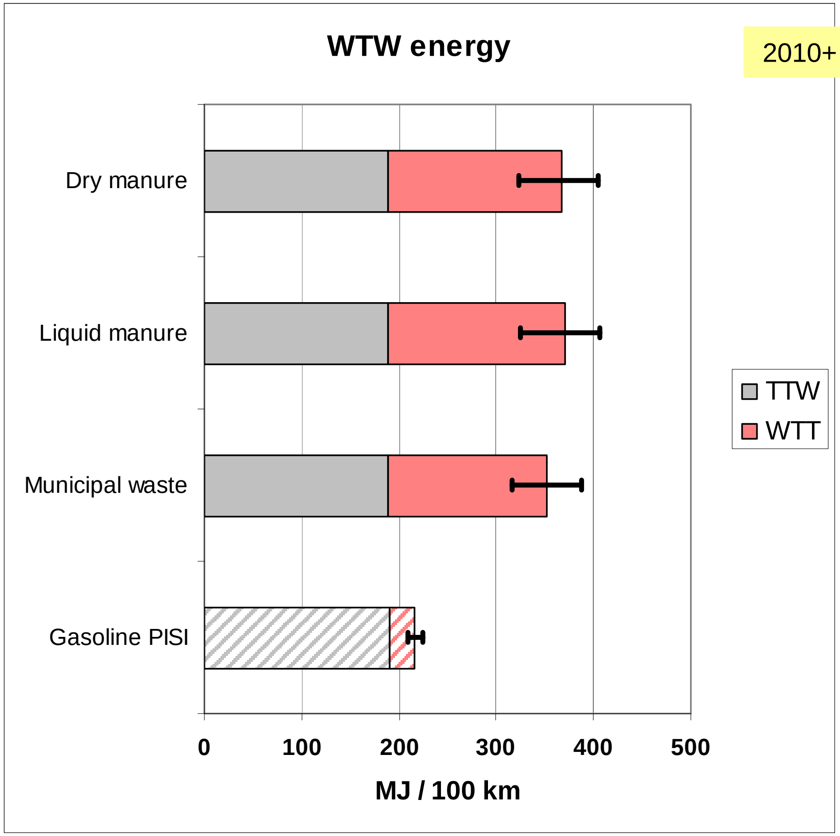
Compressed Natural Gas (CNG): key points

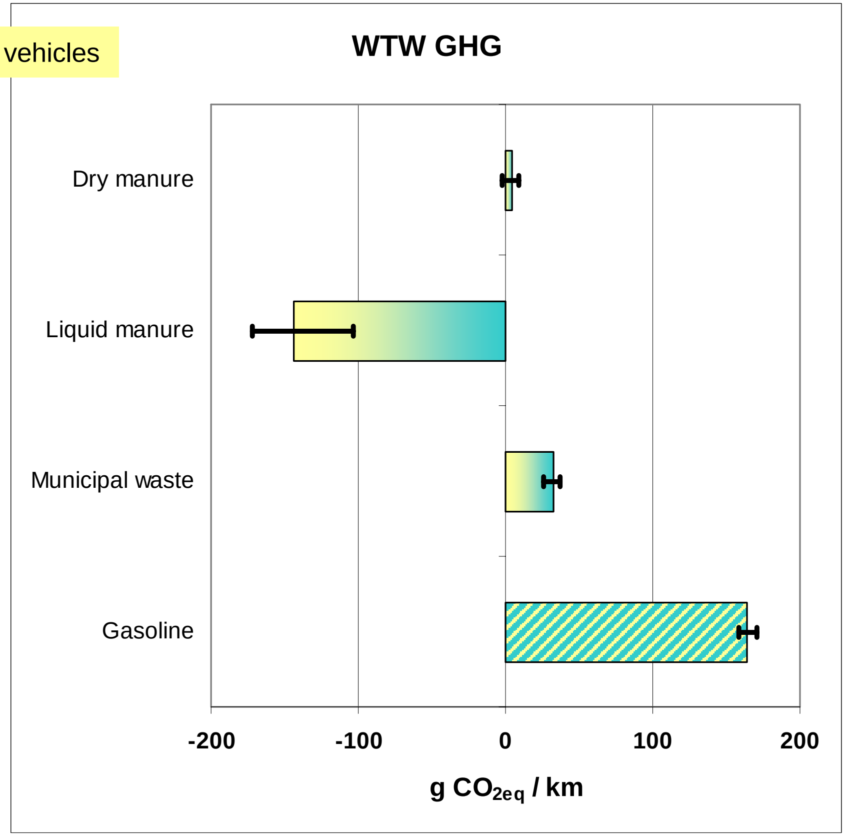
- Today the WTW GHG emissions for CNG lie between gasoline and diesel, approaching diesel in the best case

- Beyond 2010, greater engine efficiency gains are predicted for CNG vehicles, especially noticeable with hybridization
  - WTW GHG emissions become lower than those of diesel
  - WTW energy use remains higher than for conventional fuels except in the case of hybrids
  - Dedicated CNG vehicles perform only marginally better than bi-fuel vehicles

- The origin of the natural gas and the supply pathway are critical to the overall WTW energy use and GHG emissions
  - Longer supply routes become more prevalent in the future
  - Energy to transport NG through pipeline may decrease because of higher pressure pipelines

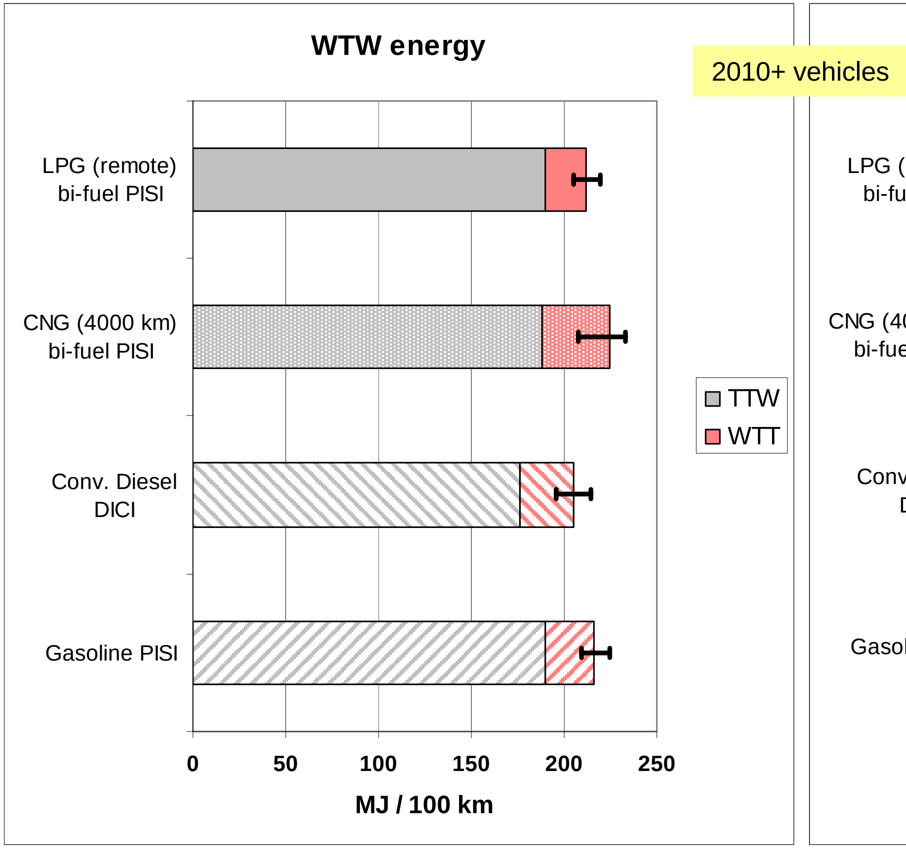
Compressed Biogas (CBG)

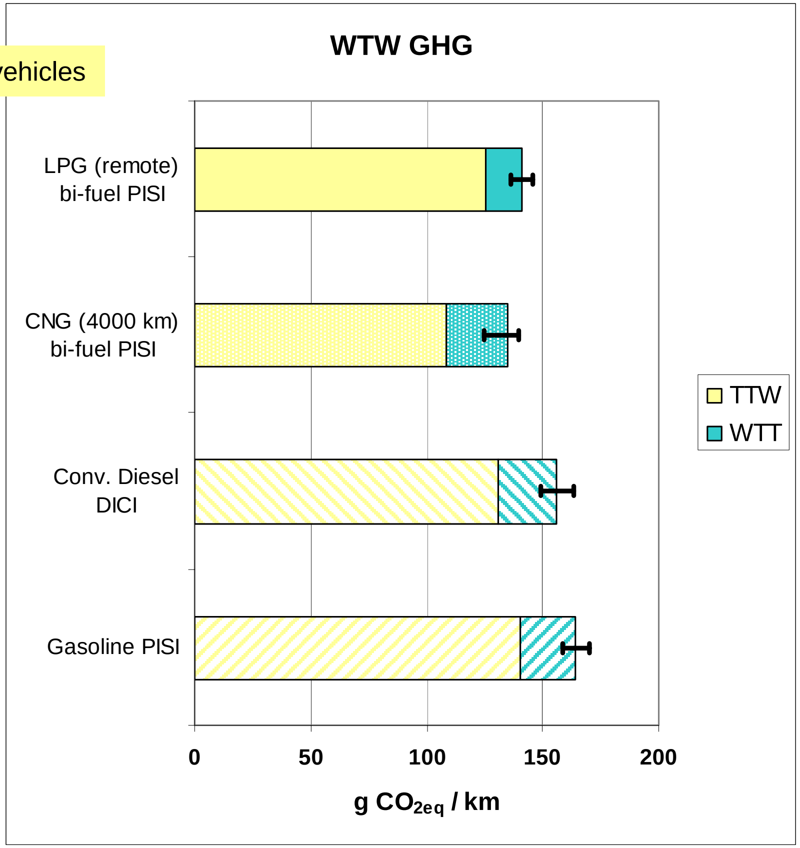




- Because it uses a waste product, biogas has a favourable GHG balance
- Using wet manure in this way stops methane emissions to atmosphere, the result of intensive livestock rearing rather than an intrinsic quality of biogas

LPG (from remote gas fields)





- **LPG's GHG emissions lie between diesel and CNG and energy between gasoline and diesel**
- **Transport distance has a significant impact**
  - **Assumption is 5500 nautical miles, i.e. Middle East origin**

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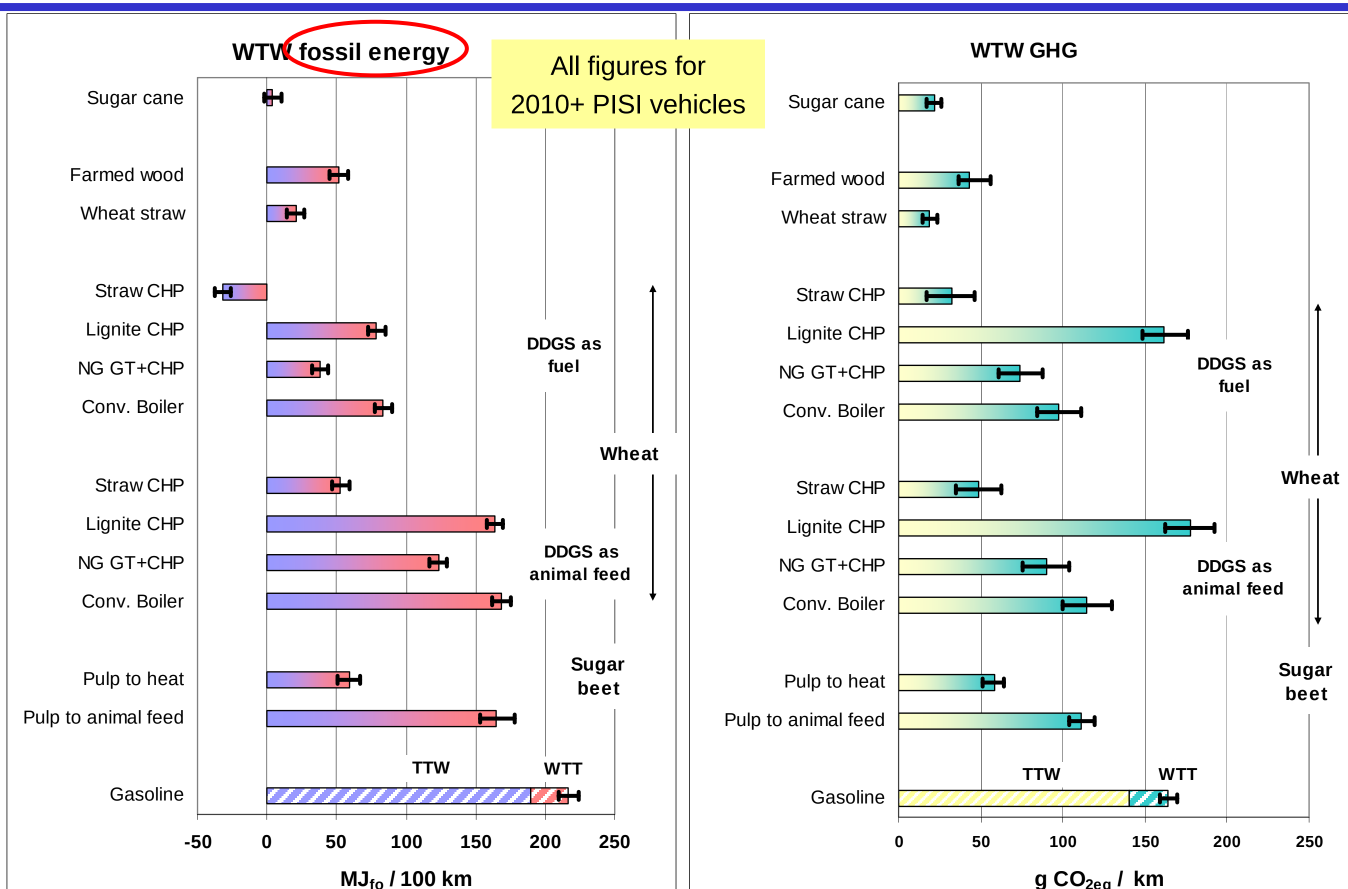
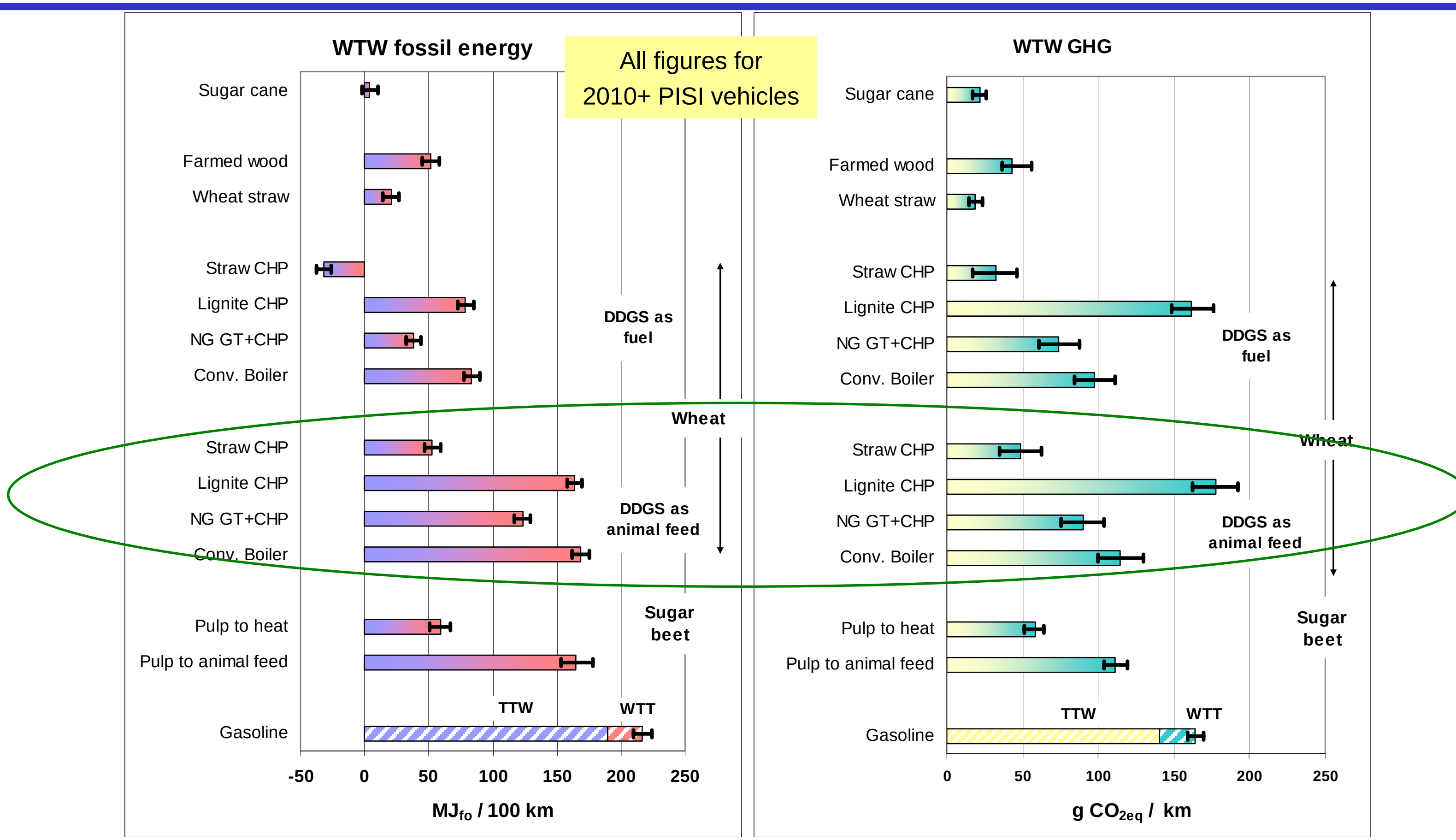
Ethanol



- Conventional production of ethanol as practiced in Europe gives modest fossil energy/GHG savings compared with gasoline
  - Existing European pathways can be improved by use of co-generation and/or use of by-products for heat
  - Choice of crop and field N_2O emissions play a critical part
  - Advanced processes (from wood or straw) can give much higher savings

Ethanol



- **Ethanol production is energy-intensive:**
  - **The production process (o/a use of CHP) and the energy source are critical**
  - **Using (brown) coal could result in increased GHG emissions even with CHP!**
  - **Using straw as fuel would obviously yield the best GHG balance**

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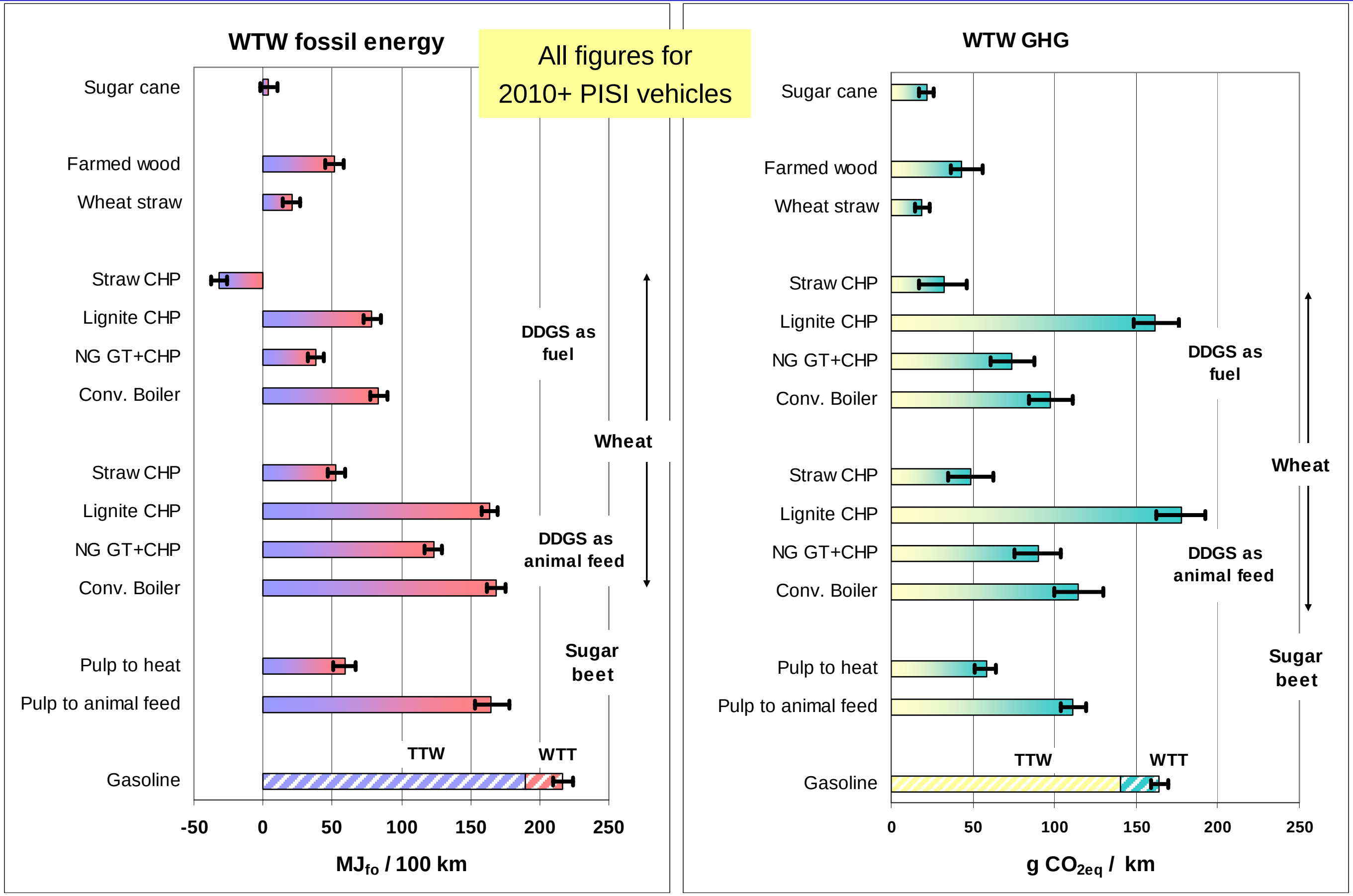
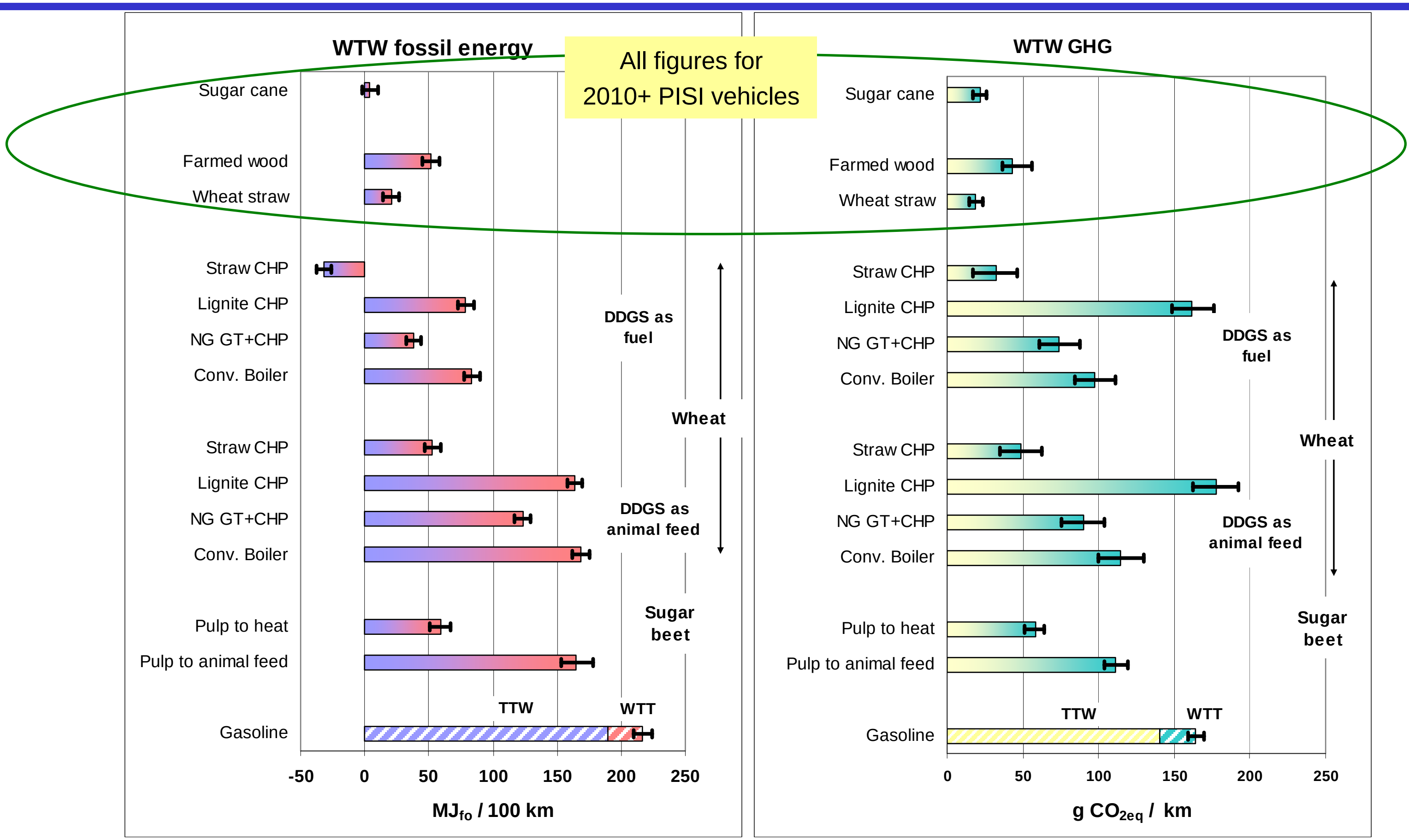
Ethanol



- Use of by-products for energy yields lowest GHG emissions. Economics are likely to favour other uses, at least short term:
  - Sugar beet pulp
  - Wheat DDGS

Ethanol



- **Use of cellulosic material is promising**
- **Sugar cane uses very little fossil energy (transport only)**

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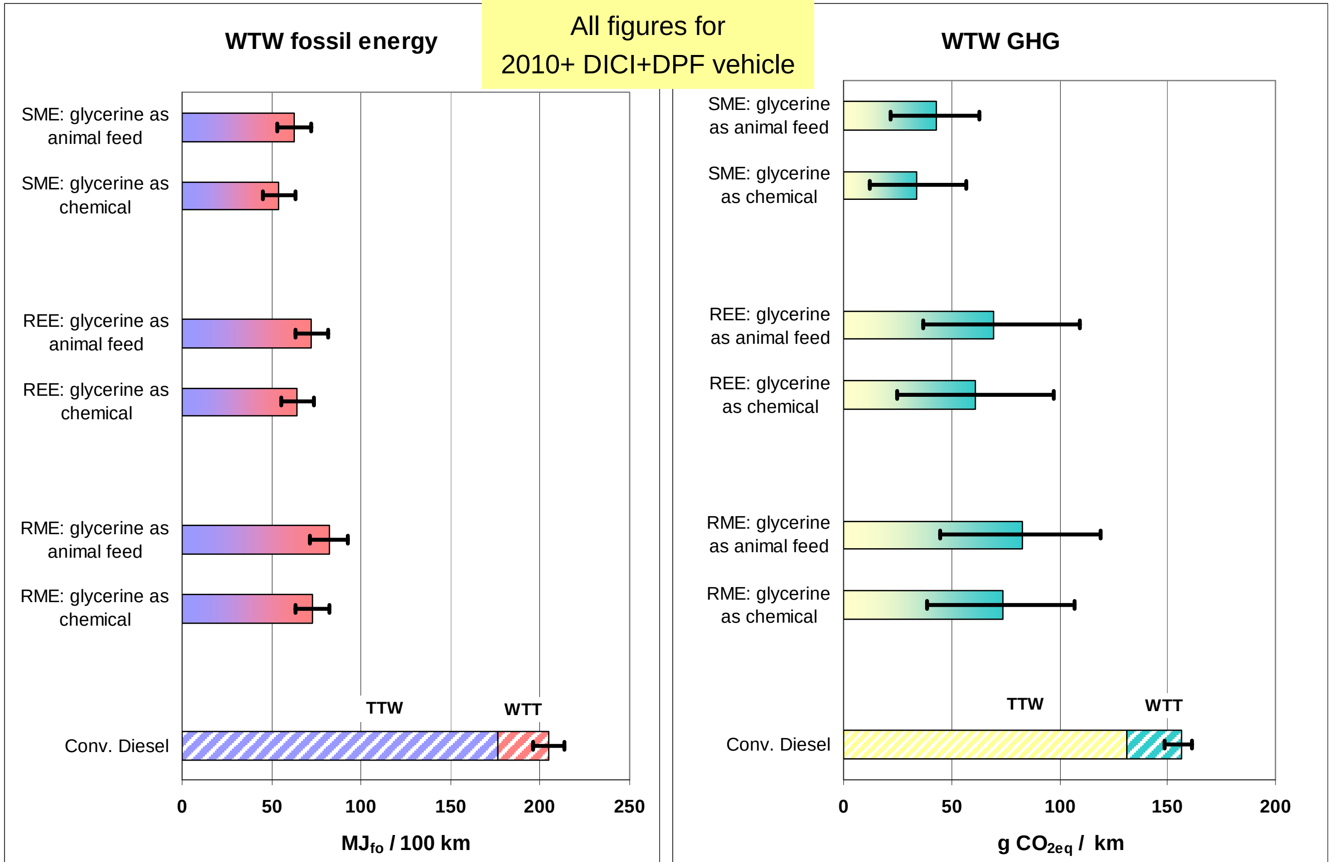
Bio-diesel



- **Bio-diesel saves fossil energy and GHG compared to conventional diesel**
  - **Field N_2O emissions play a big part in the GHG balance and are responsible for the large uncertainty**
  - **Use of glycerine has a relatively small impact**
  - **Sunflower is more favourable than rape**

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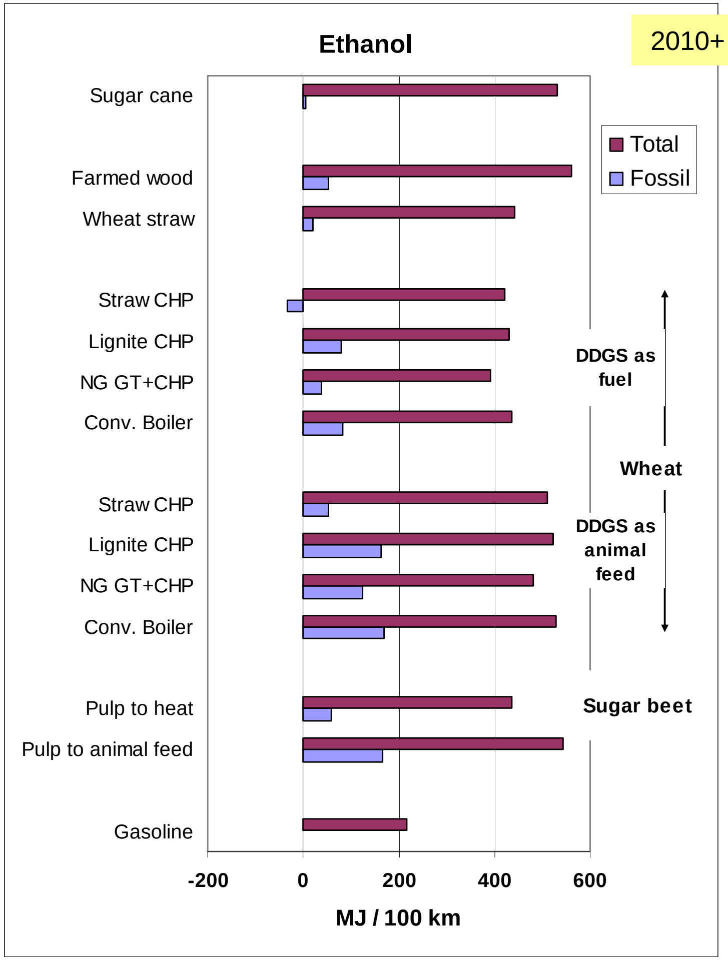
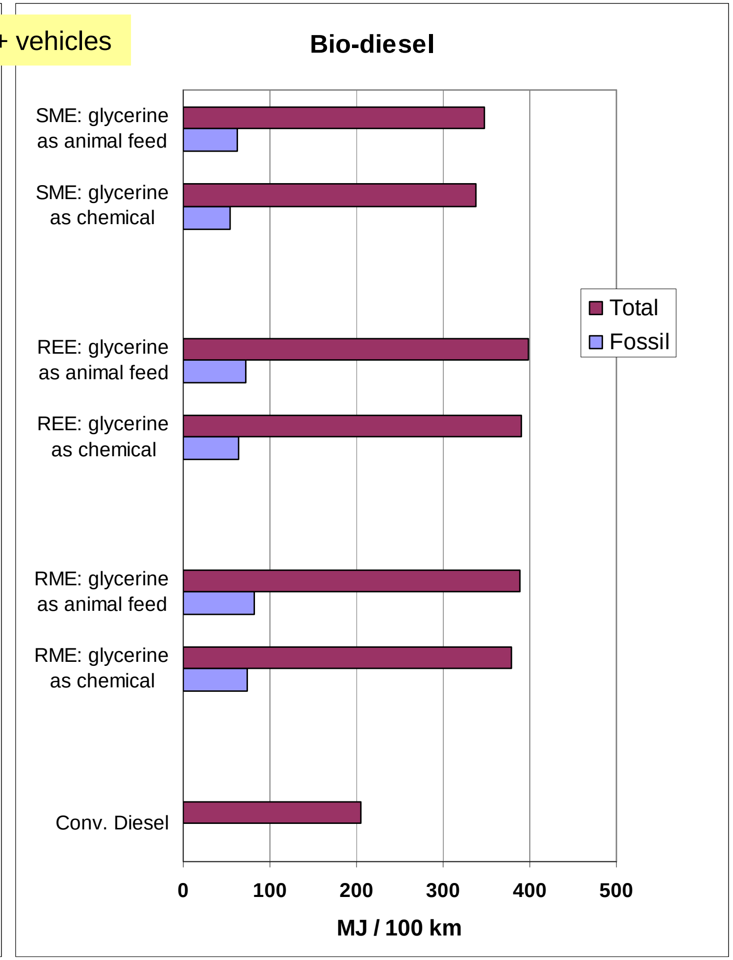
Bio-fuels: fossil and total energy





- **The conversion of biomass into conventional bio-fuels is not energy-efficient**
  - **Ethanol and bio-diesel require more bio-energy than the fossil energy they save**

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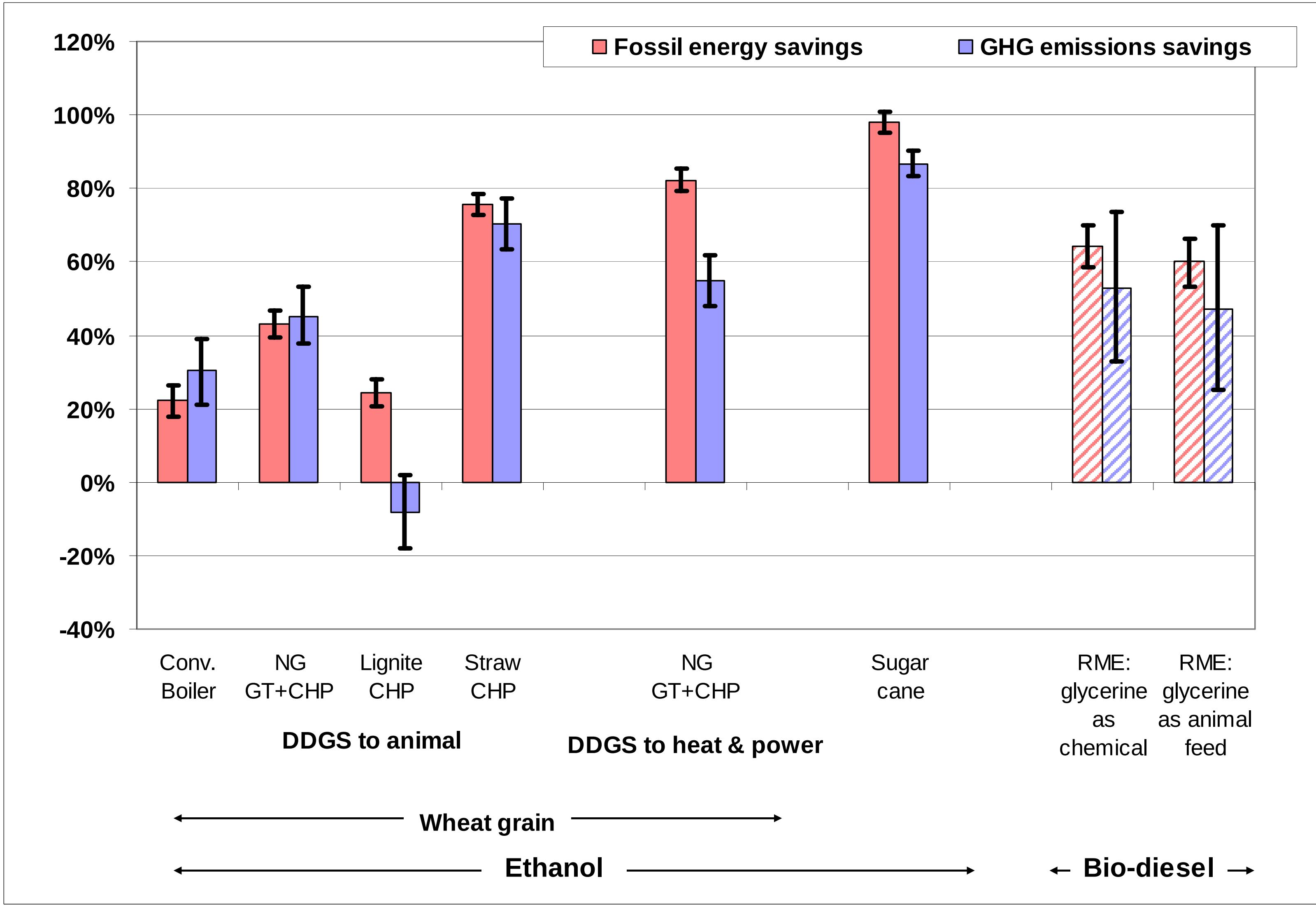
Bio-fuels: Energy and GHG avoidance



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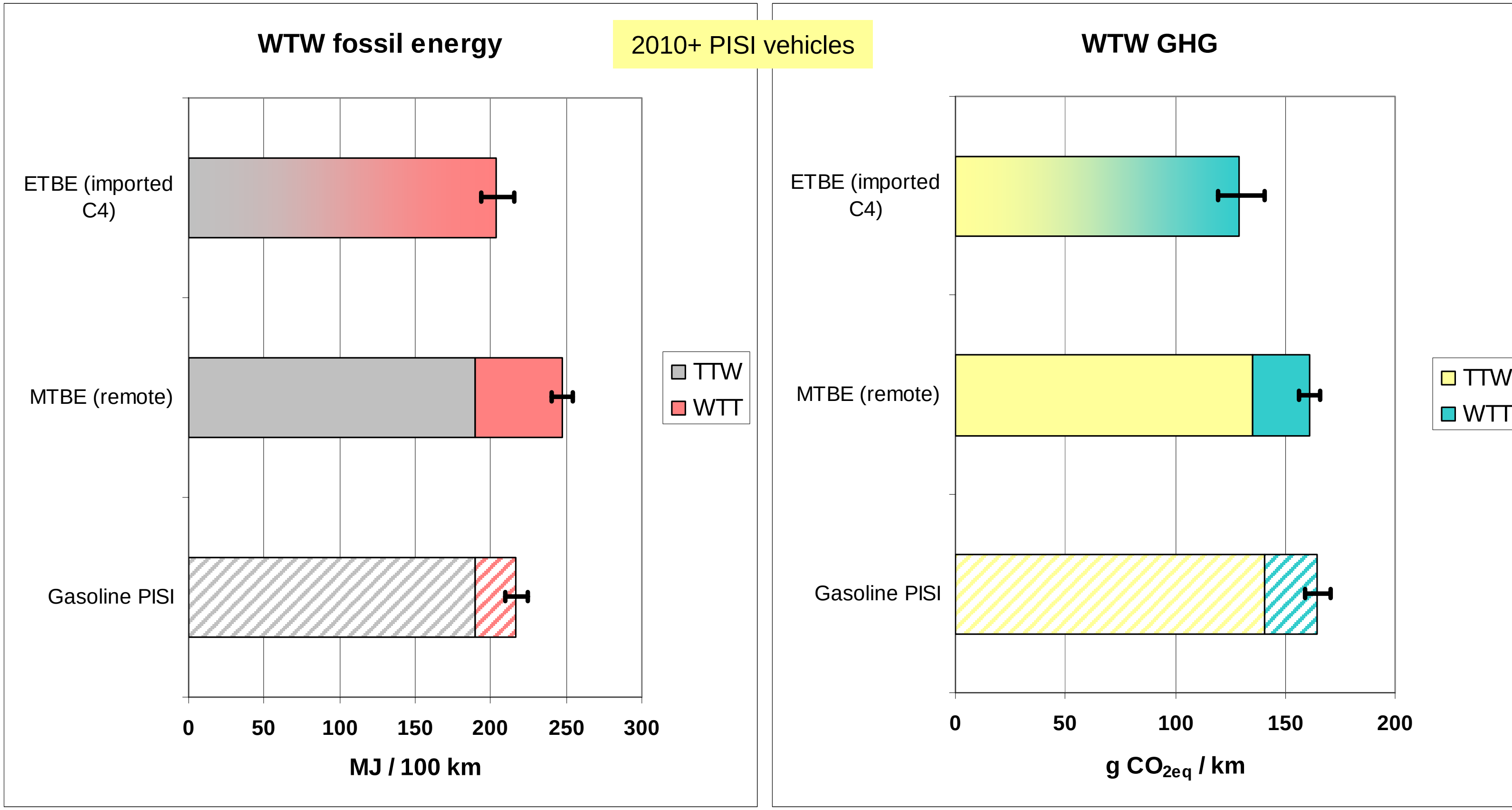
Ethers (large scale)



Ethanol for ETBE deemed to be from wheat (NG CCGT, DDGS to animal feed)

- **MTBE is slightly more energy-intensive than gasoline and GHG- neutral**
- **The “bio-content” of ETBE brings a 20% saving of fossil energy and GHG**

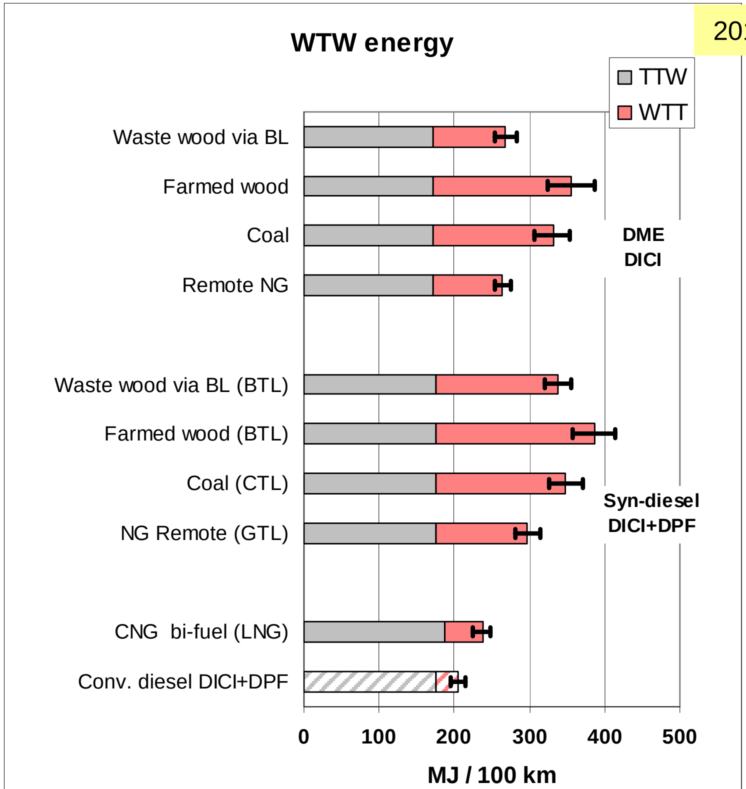
Ethers: the special case of MTBE/ETBE from refineries

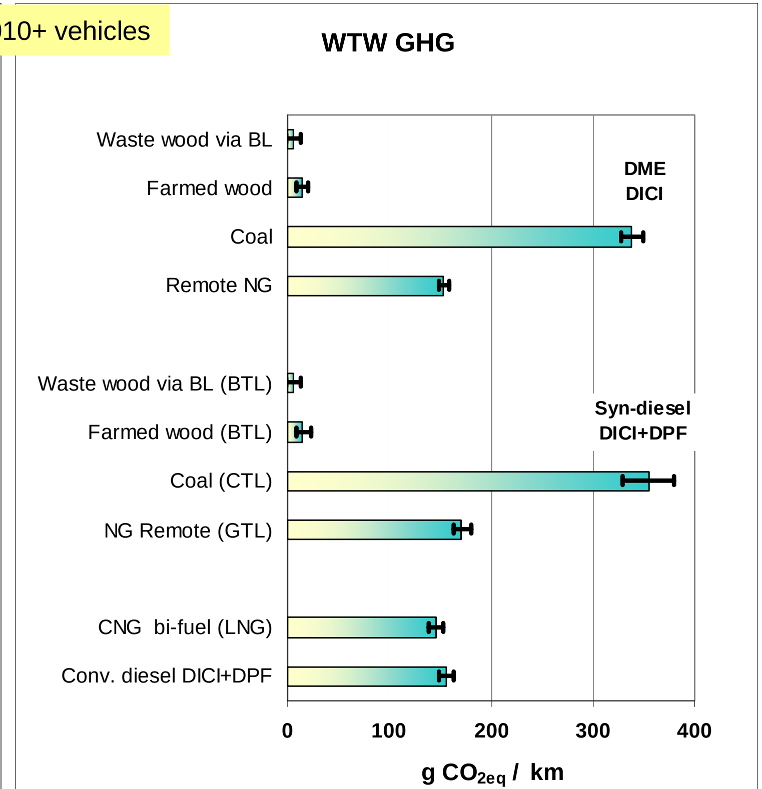
- A realistic estimate of the energy and GHG emissions attached to MTBE/ETBE production in refineries cannot be made because it is part of a complex set of integrated processes
- In order to evaluate the impact of switching from MTBE to ETBE in refineries we have considered two alternative uses of ethanol:
  - As ethanol: a corresponding amount of refinery MTBE is used in gasoline blending
  - As ETBE, substituting refinery MTBE: methanol is saved and additional standard gasoline is required
  - The net effect is to replace methanol by additional gasoline
  - The balance shows the ETBE case to be more energy and GHG-efficient

Use of ethanol	Fossil energy MJ_{xfo}/MJ_{EtOH}	GHG g CO_{2eq} / MJ_{EtOH}
As ethanol	0.65	46.6
As ETBE	0.39	42.0
Gasoline (for ref.)	*1.14*	*85.9*

  - The reduction of fossil energy is substantial because methanol manufacture is energy-intensive compared to gasoline
  - The impact on GHG emissions is more limited because the fossil energy for methanol is gas rather than oil-based

Syn-diesel and DME

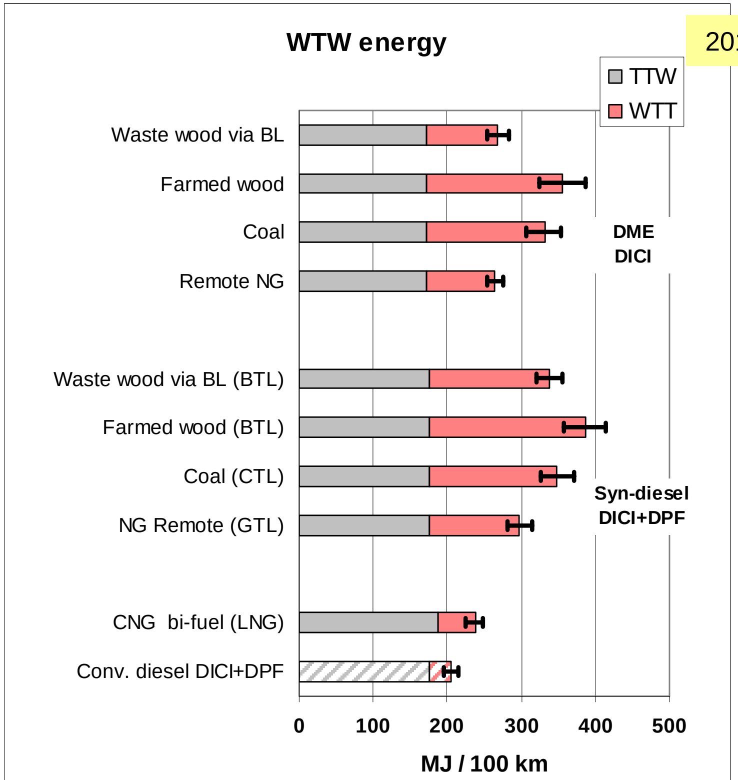


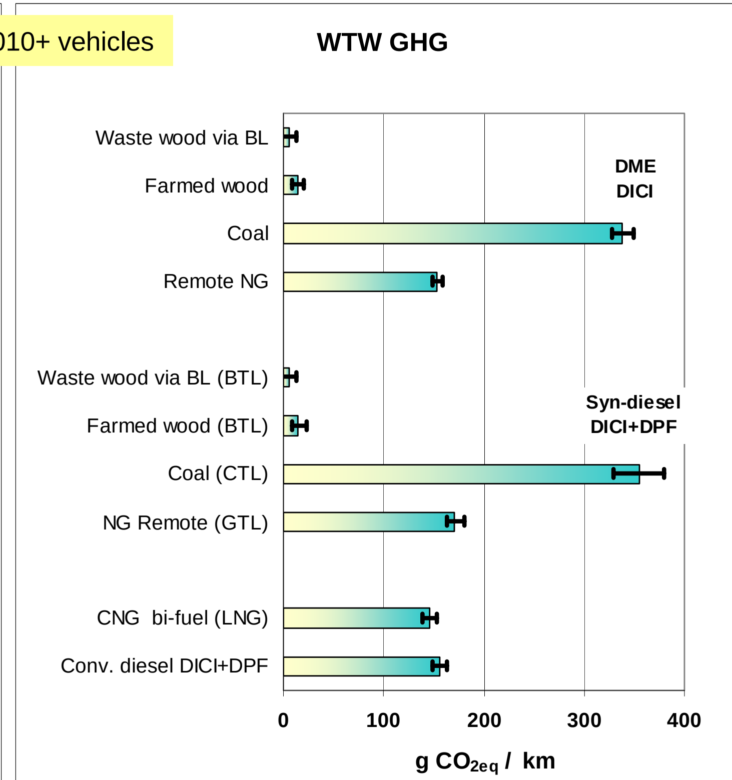


- Diesel synthesis requires more energy than conventional diesel refining from crude oil
- GHG emissions from syn-diesel from NG (GTL) are slightly higher than those of conventional diesel, syn-diesel from coal (CTL) produces considerably more GHG
- The use of biomass (BTL processes) involves very little fossil energy and therefore produces little GHG emissions because the synthesis processes are fuelled by the biomass itself

Syn-diesel and DME

2010+ vehicles



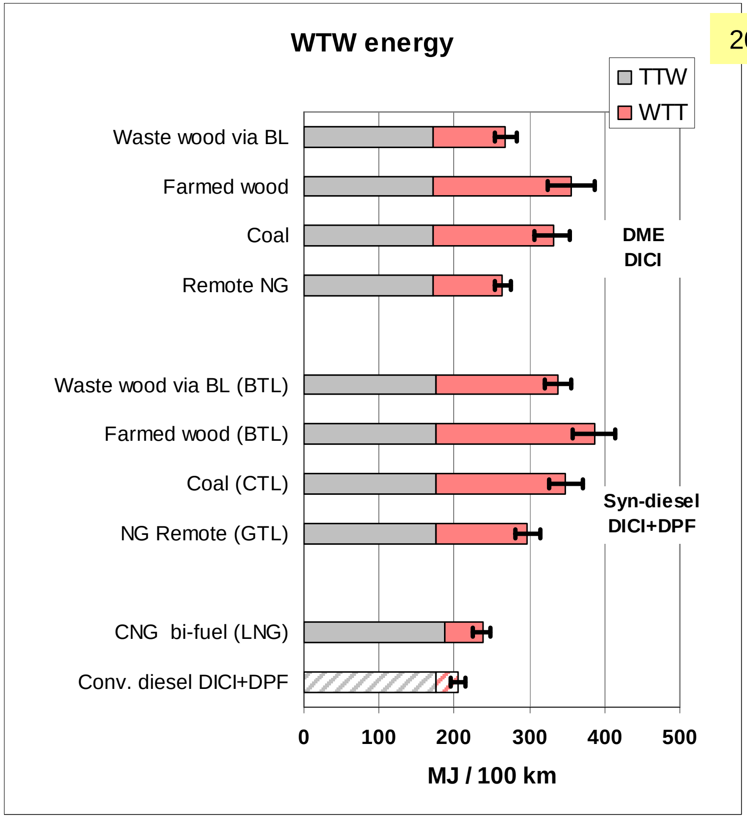


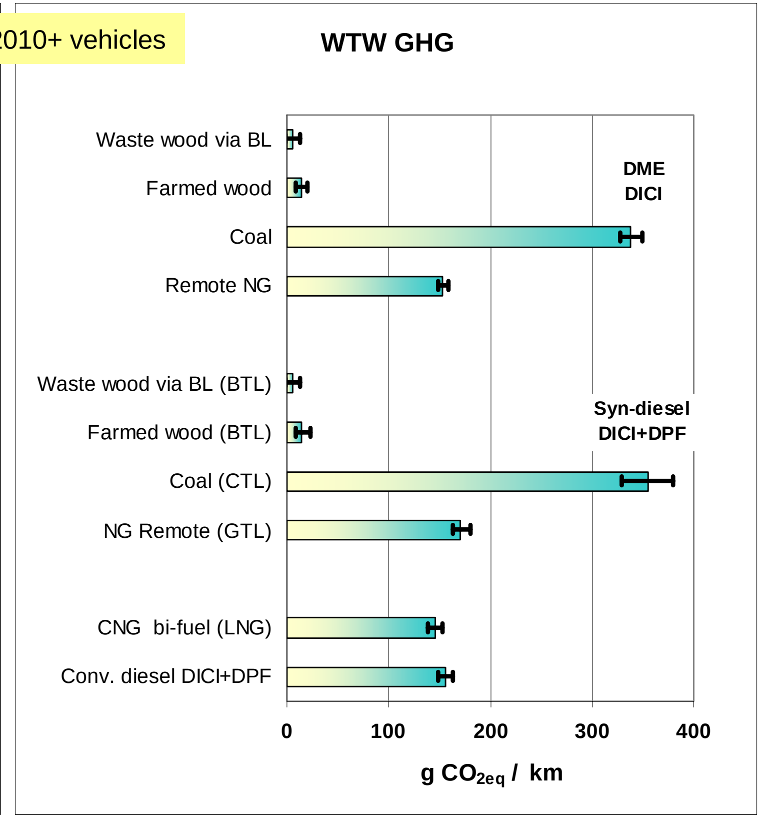
- **DME can be produced from natural gas or biomass at lower energy use and GHG emissions than syn-diesel**
- **Use of DME as automotive fuel would require modified vehicles and infrastructure similar to LPG**

- **The “black liquor” route offers higher wood conversion efficiency although the scope for practical applications will be determined by the specific circumstances of the pulp and paper industry**

Syn-diesel and DME

2010+ vehicles





- **Use of remote natural gas through CNG via LNG delivers lower energy consumption and GHG emissions than through GTL or DME**

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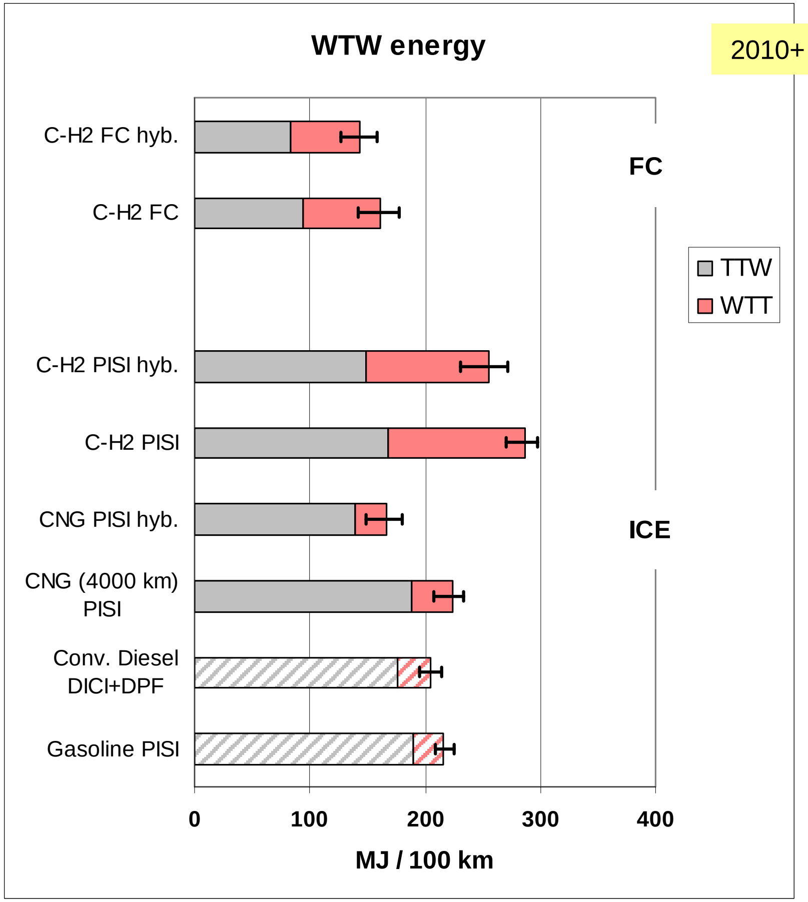
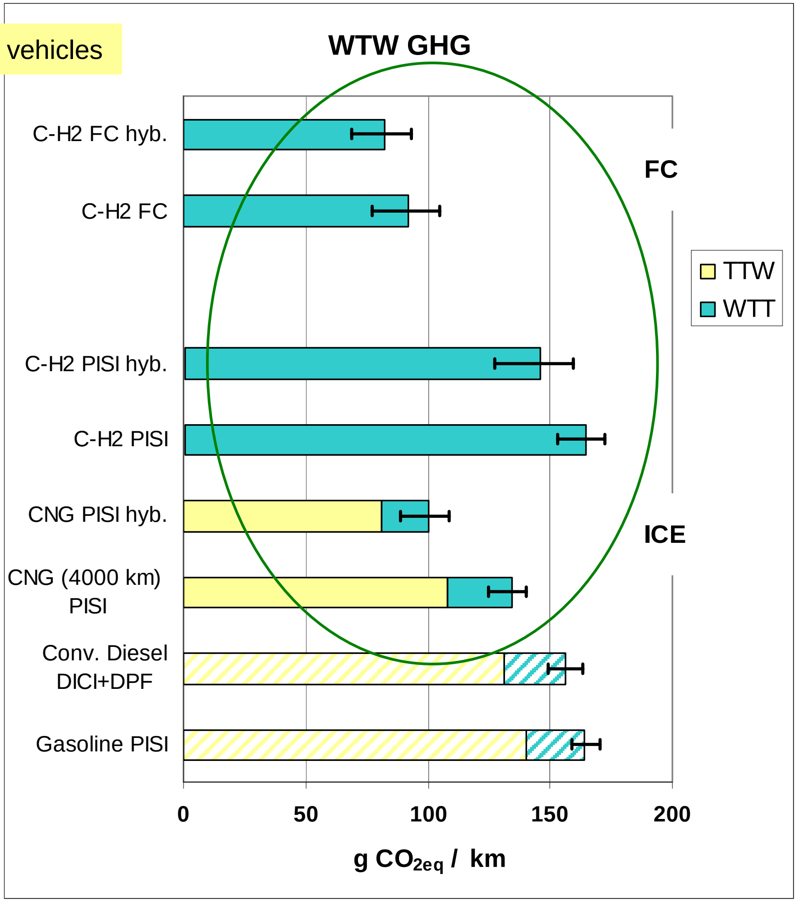
Alternative Liquid Fuels: key points

- A number of routes are available to produce alternative liquid fuels that can be used neat or in blends with conventional fuels in the existing infrastructure and vehicles
- Conventional bio-fuels (ethanol, FAME) provide fossil energy and GHG savings but conversion is less energy-efficient than for conventional fuels
  - The GHG balance of conventional biofuels is particularly uncertain because of N_2O emissions
- Syn-diesel from NG (GTL) is nearly GHG neutral compared to conventional diesel, syn-diesel from coal (CTL) produces considerably more GHG
- New processes are being developed to produce synthetic fuels from biomass (BTL) with lower overall GHG emissions, though still high energy use
- DME can be produced from natural gas or biomass at lower energy use and GHG emissions than other GTL or BTL fuels
  - But would require specially modified vehicles and fuel distribution infrastructure
- The “black liquor” route offers higher wood conversion efficiency although the scope for practical applications will be determined by the specific circumstances of the pulp and paper industry

Hydrogen from NG : ICE and Fuel Cell

2010+ vehicles





If hydrogen is produced from NG, GHG emissions savings are only achieved with fuel cell vehicles

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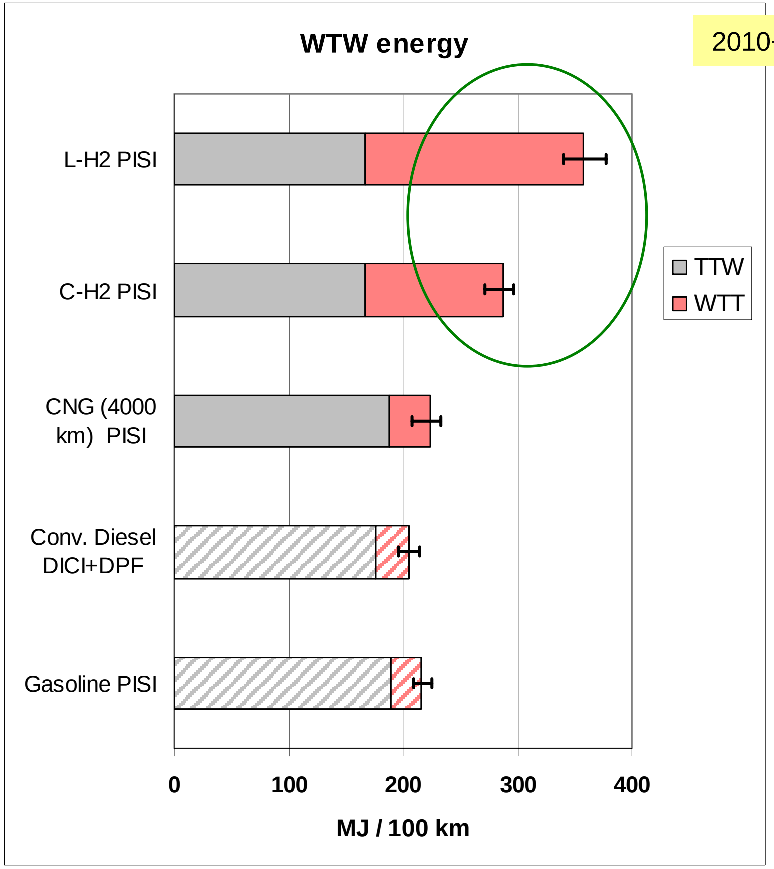
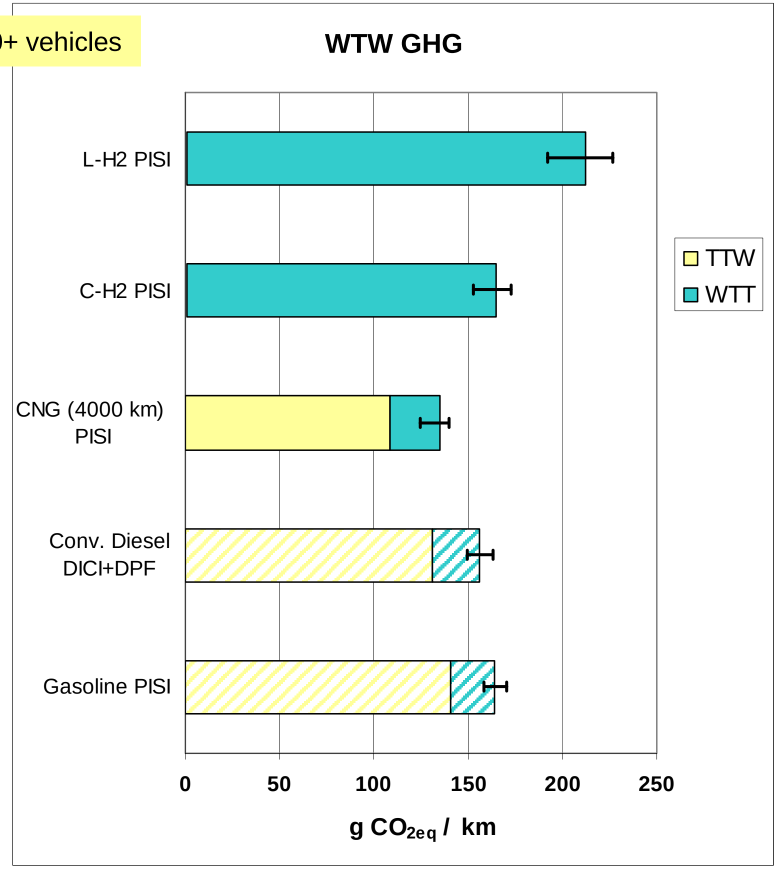
Hydrogen from NG : Compressed v. Liquid

2010+ vehicles

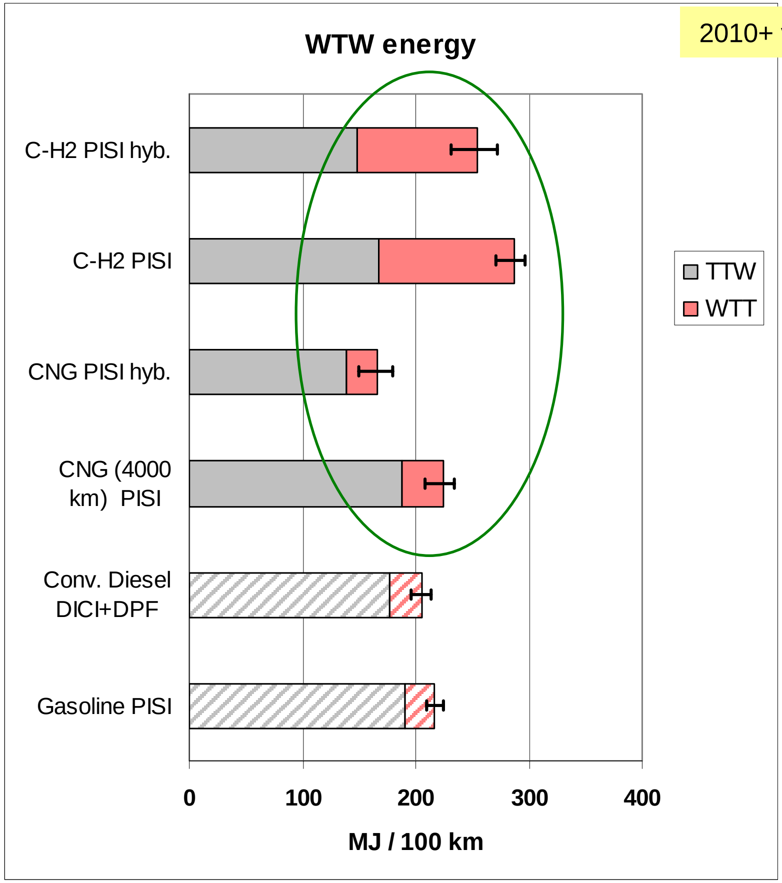


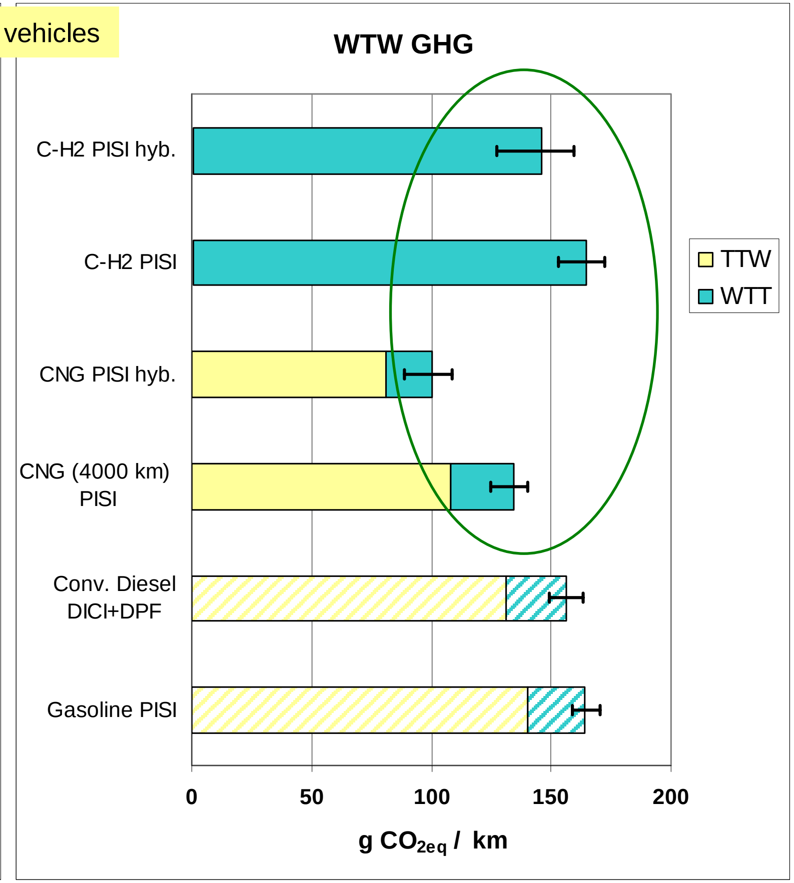


Liquid hydrogen is less energy efficient than compressed hydrogen

Hydrogen from NG : hydrogen v. CNG ICE

2010+ vehicles



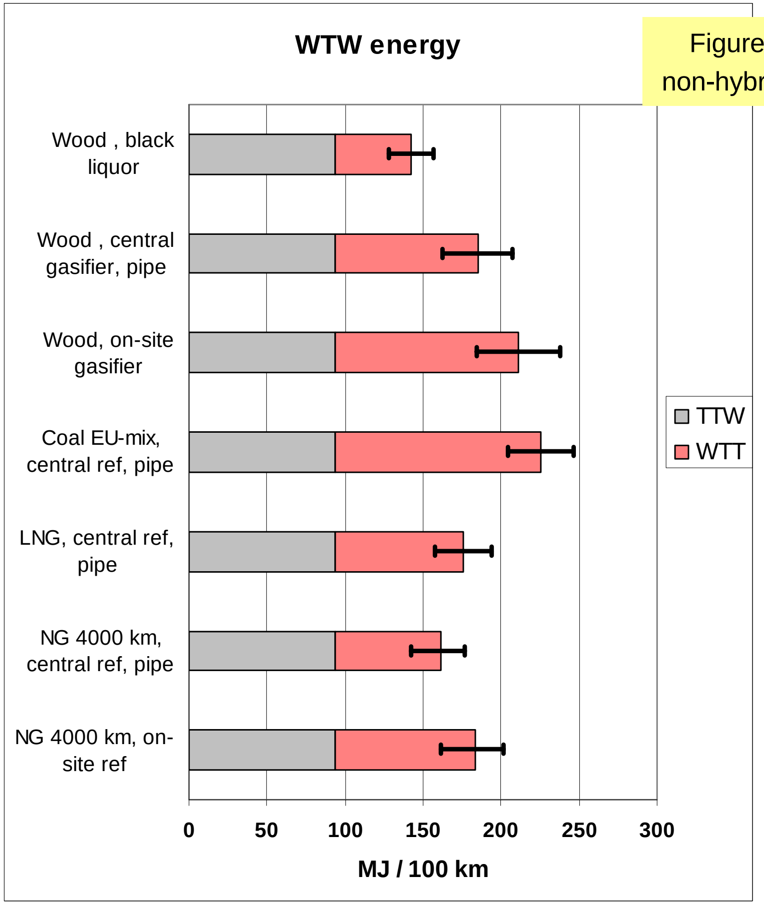


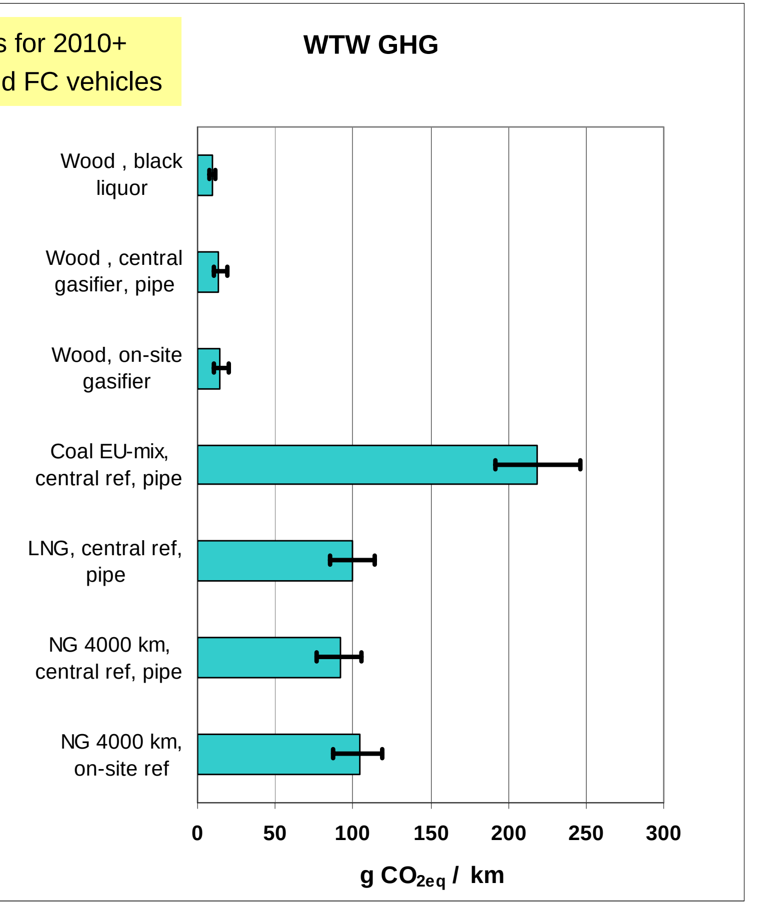
For ICE vehicles, direct use of NG as CNG is more energy/GHG efficient than hydrogen

Impact of hydrogen production route : fuel cell vehicles

Direct hydrogen production via reforming

Figures for 2010+
non-hybrid FC vehicles





Hydrogen from renewables gives low GHG
But comparison with other uses is required

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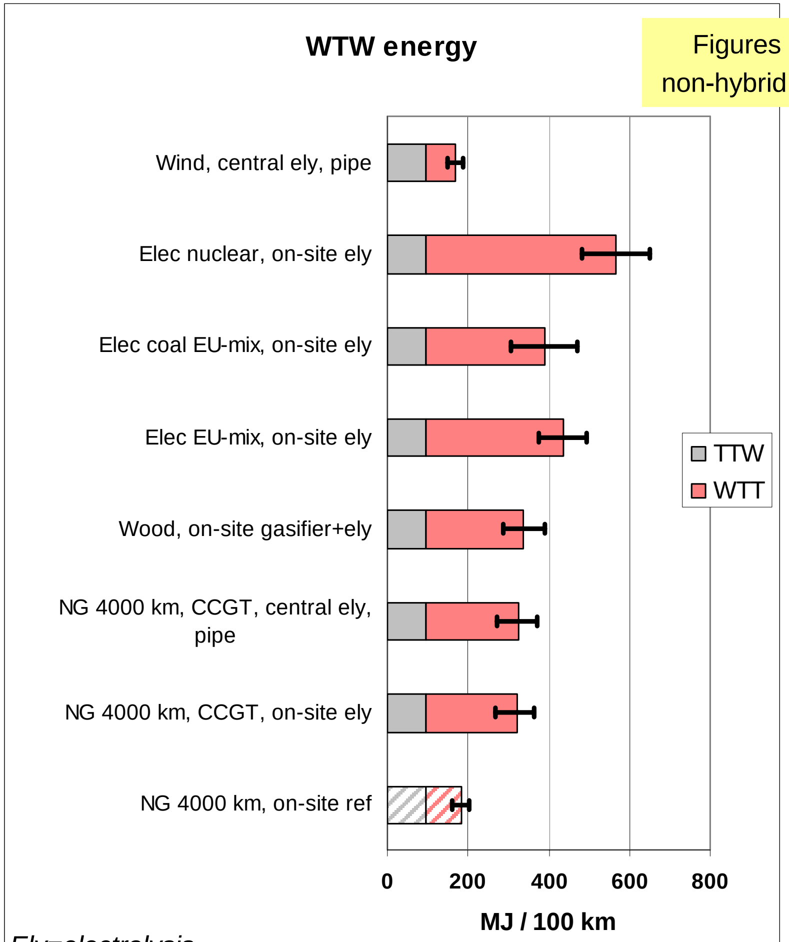
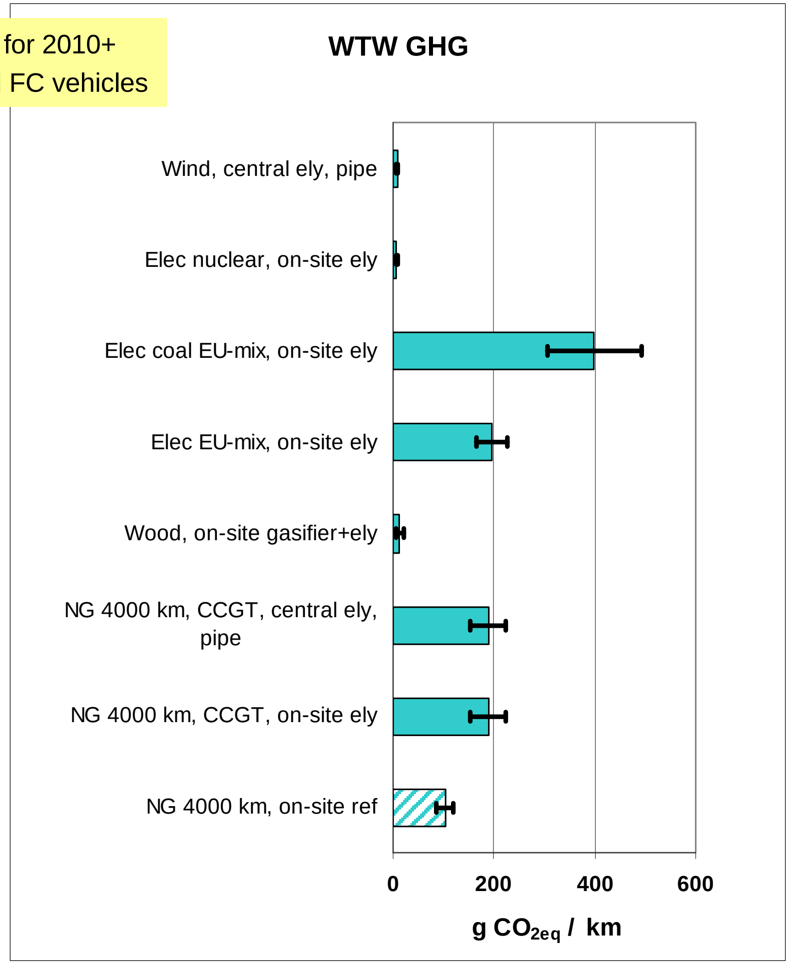
Impact of hydrogen production route : fuel cell vehicles

Hydrogen production via electrolysis





Ely=electrolysis

Electrolysis is less energy efficient than direct hydrogen production

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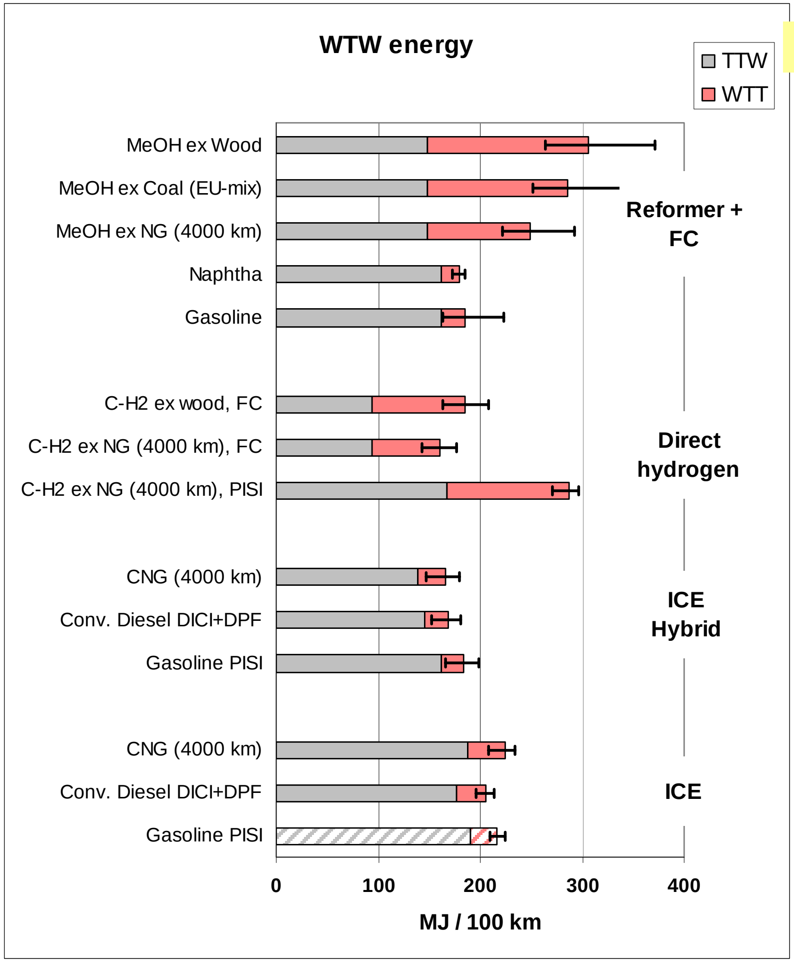
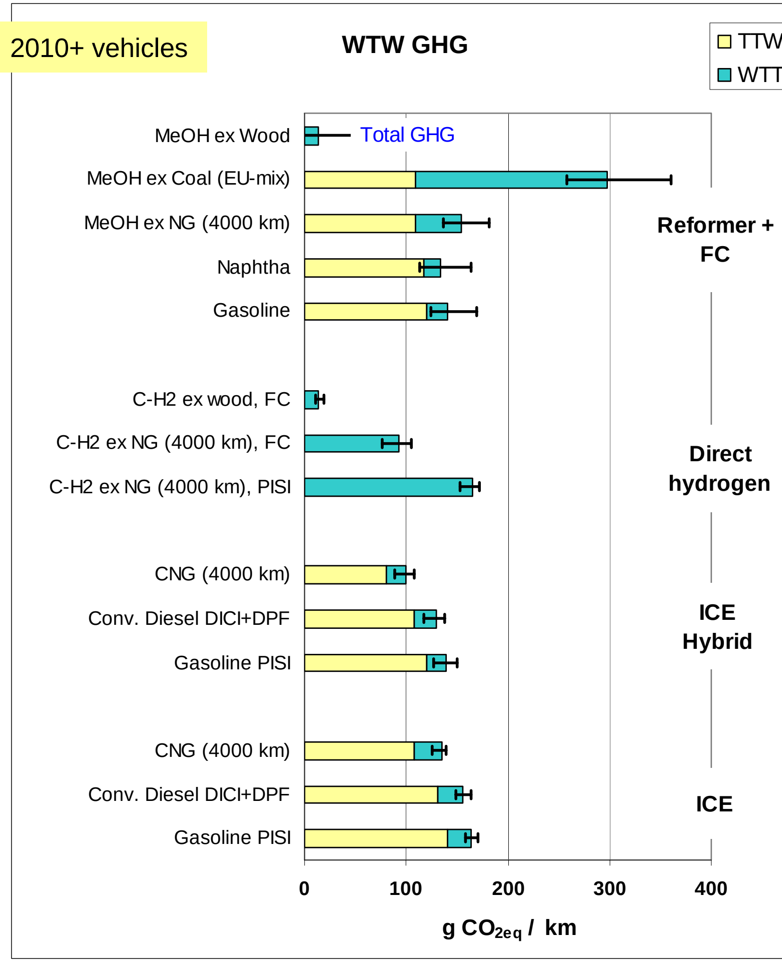
Impact of hydrogen production route: on-board reformers

2010+ vehicles



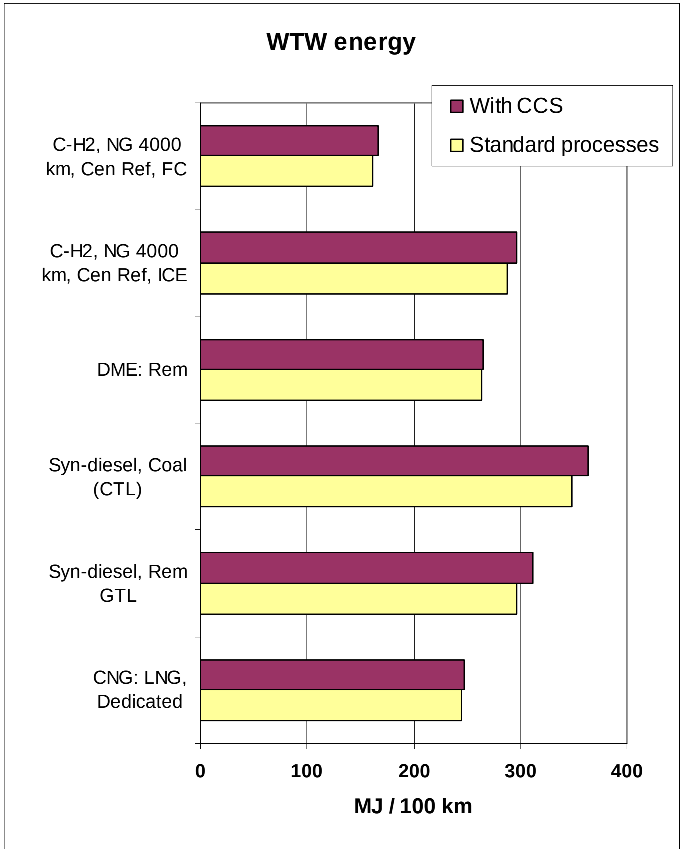


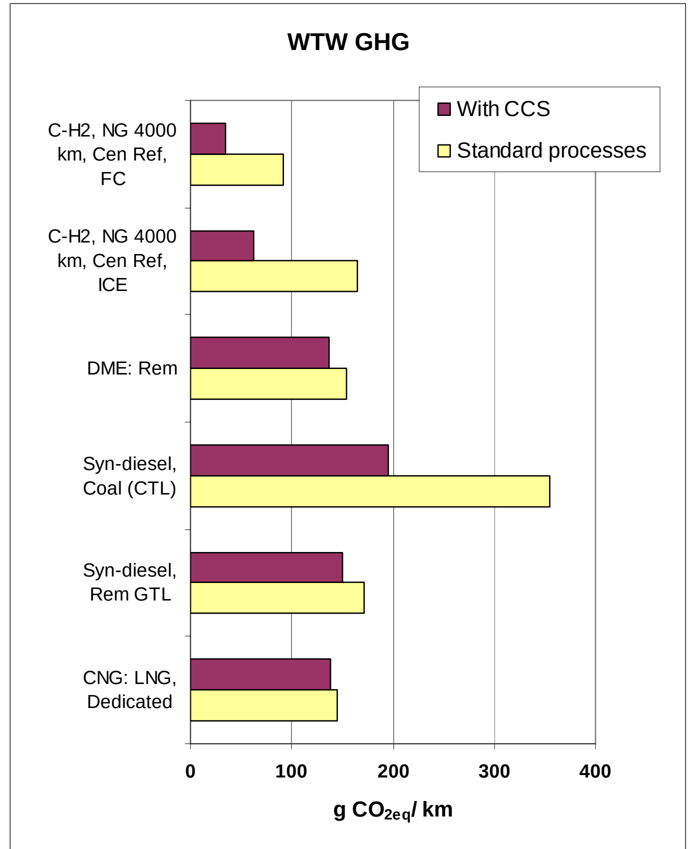
- **On-board reforming of gasoline/naphtha matches 2010 hybrid performance**
- **Could provide supply flexibility during fuel cell introduction**

CO_2 capture and storage (CC&S)

- The concept of isolating CO_2 produced in combustion or conversion processes and injecting it into suitable geological formations has been gaining credibility in the last few years
- There is considerable scope for storage in various types of geological formations
- CO_2 capture and transport technologies are available
  - Easier when CO_2 is produced in nearly pure form
  - Transport in supercritical state (compressed) by pipeline or ship
- The main issues are
  - Long-term integrity and safety of storage
  - Legal aspects
  - Cost
- The complete technological packages are under development
  - CO_2 removal potential given here is only indicative
- Preliminary assessment based on data from the IEA greenhouse gas group and other literature sources
- Cost data not included as available info not considered sufficiently reliable and consistent

CO_2 capture and storage (CC&S)





- **CC&S requires some additional energy (mainly for CO_2 compression)**
- **It is most attractive for**
  - **Processes that use large amounts of high-carbon energy (CTL)**
  - **Processes that "decarbonise" the fuels (hydrogen)**

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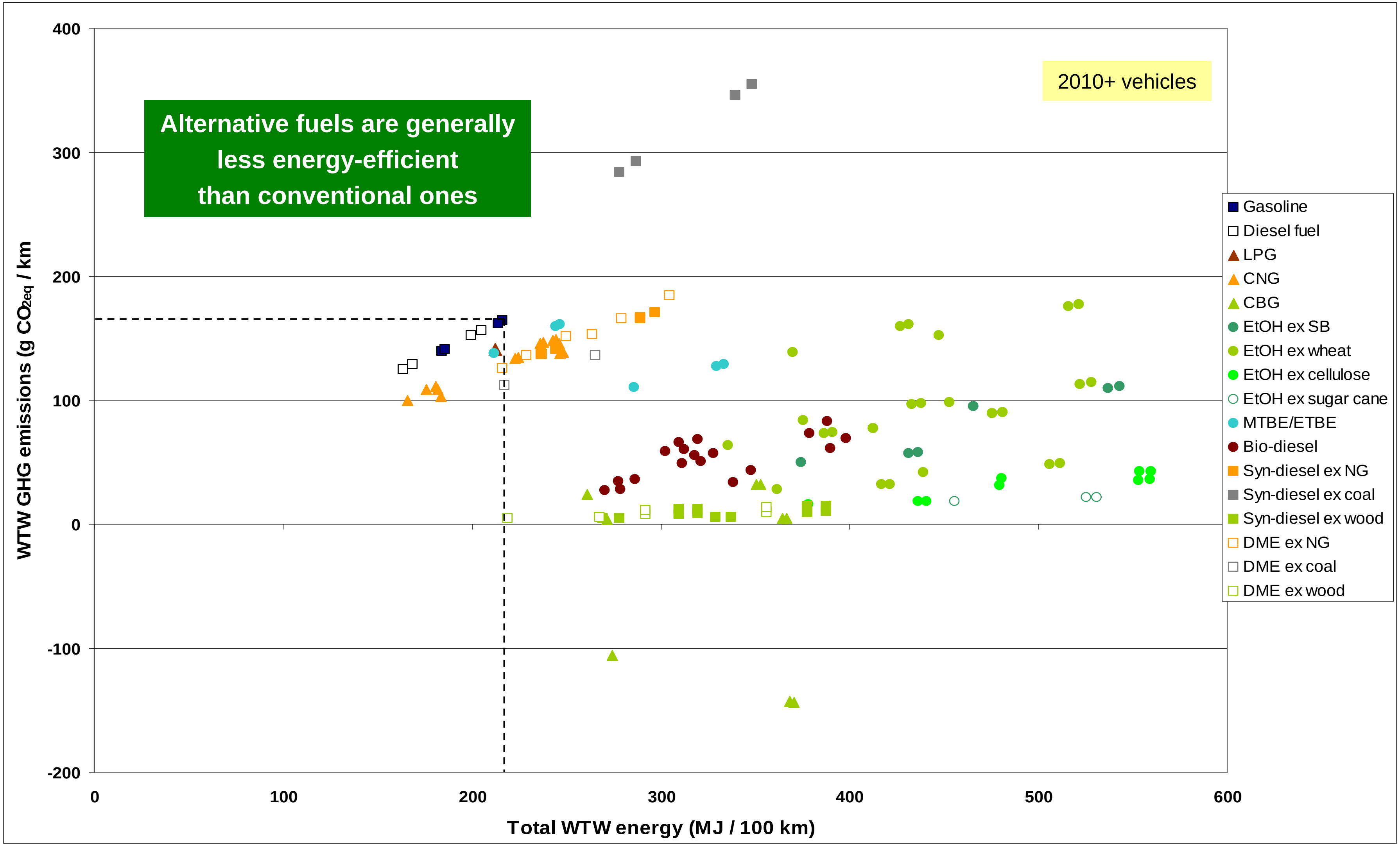
Overall picture: GHG versus total energy

Liquid fuels, DME/LPG/CNG/CBG



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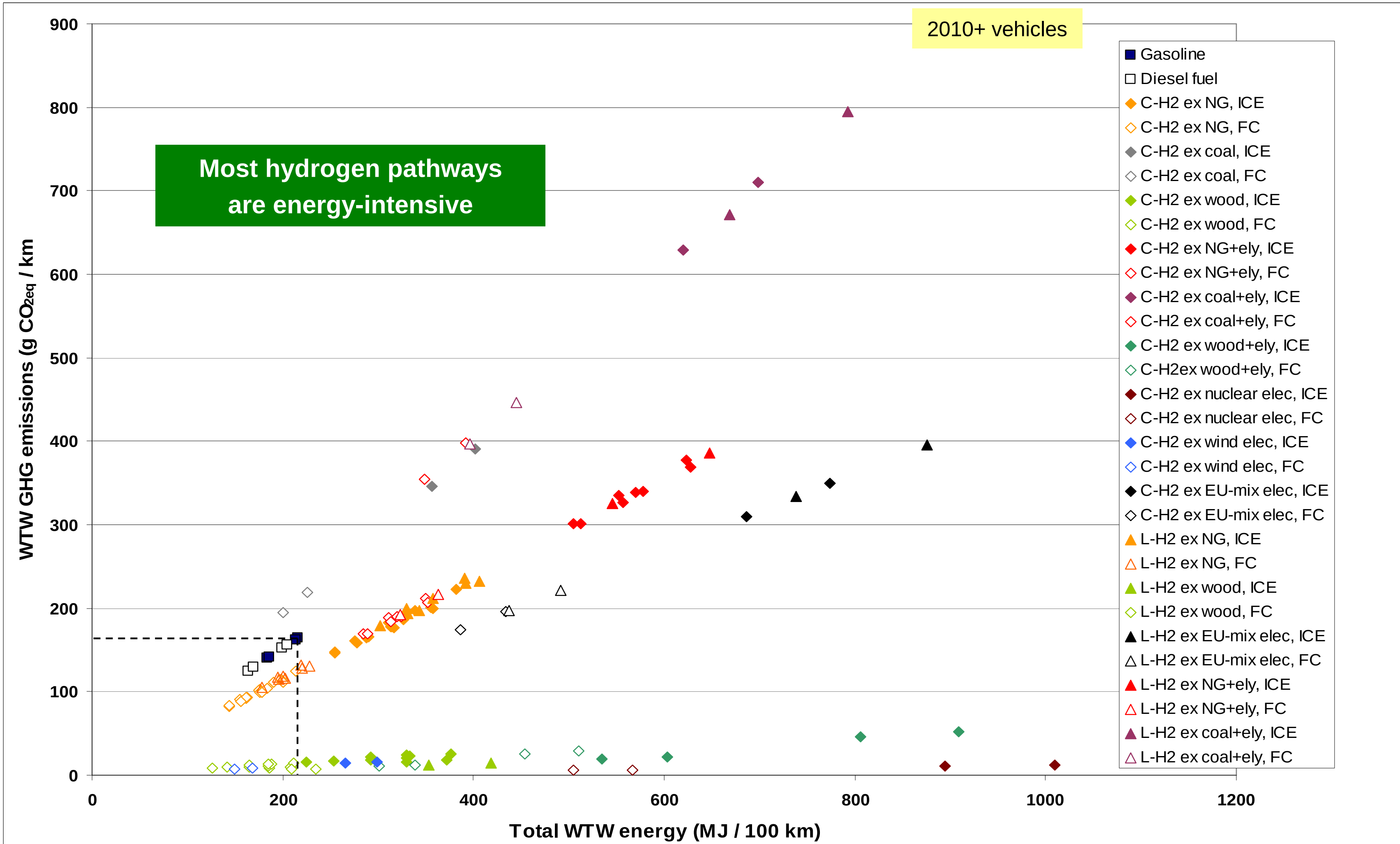
Overall picture: GHG versus total energy

Hydrogen



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Cost of fossil fuels substitution and CO_2 avoided

- Some cost elements are dependent on scale (e.g. distribution infrastructure, number of alternative vehicles etc)
- As a common calculation basis we assumed that 5% of the relevant vehicle fleet (SI, CI or both) converts to the alternative fuel
  - This is not a forecast, simply a way of comparing each fuel option under the same conditions
  - If this portion of the EU transportation demand were to be replaced by alternative fuels and powertrain technologies, the GHG savings vs. incremental costs would be as indicated
- Costs of CO_2 avoided are calculated from incremental capital and operating costs for fuel production and distribution, and for the vehicle

The costs, as calculated, are valid for a steady-state situation where 5% of the relevant conventional fuels have been replaced by an alternative. Additional costs are likely to be incurred during the transition period, especially where a new distribution infrastructure is required.

Costing basis

- We considered the cost from a macro-economic point of view (cost to "EU inc.")
  - The cost of internationally traded commodities is the market price whether imported or produced within Europe (unless the production cost in Europe is higher)
  - The 12% capital charge excludes the tax element (internal)
- Cost elements considered
  - For fuels produced within Europe
    - Raw material cost
    - Production cost (capital charge + fixed operating costs + energy/chemicals costs)
  - For imported fuels: market price
  - Distribution and retail costs
  - Additional cost of alternative vehicles (compared to state-of-the-art gasoline PISI)

Costing basis: oil price

- Oil price is important because
  - It sets the cost of fossil fuels
  - It influences the cost of virtually all other materials and services
- We have considered two oil price scenarios
  - 25 €/bbl (30 $/bbl)
  - 50 €/bbl (60 $/bbl)
- All other cost elements are adjusted according to an "Oil Cost Factor" (OCF) representing the fraction of the cost element that will follow the oil price

Cost of fossil raw materials and fuels

Crude oil	Density t/m³	LHV GJ/t	Low scenario		High scenario	
			€ /bbl	€ /GJ	€ /bbl	€ /GJ
	0.820	42.0	25	4.6	50	9.1
Natural gas		Ratio to crude		€ /GJ	OCF	€ /GJ
At EU border		0.8		3.7	1.00	7.3
Remote				2.0		4.0
Coal				€ /GJ	OCF	€ /GJ
Hard				1.5	0.65	2.5
Brown (Lignite)				1.2		2.0
Nuclear fuel				€ /GJ	OCF	€ /GJ
				1.1	0.20	1.3
Road fuels of fossil origin				€ /GJ	OCF	€ /GJ
		Ratio to crude				
Gasoline and diesel fuel		1.3		5.9	1.00	11.9
		Ratio to crude				
LPG		1.2		5.5	1.00	11.0
		Ratio to Crude				
Marine fuel oil		0.8		3.7	1.00	7.3
		Ratio to diesel				
Synthetic diesel		1.2		7.1	1.00	14.2
		Ratio to crude (t/t)				
Methanol		1.0		9.6	0.40	13.5

EU-mix electricity	Low oil price		High oil price	
	€ /MWh		OCF	€ /MWh
		Cum.		Cumulative
Production	38	38	0.50	57
MV dist.	20	58		77
LV dist.	7	65		84

Cost of biomass raw materials

Based on FAPRI 2012 projections

Delivered to processing plant

	Moisture content	LHV	Low oil price (oil at 25 €/bbl)		Own	High oil price		
						OCF	(oil at 50 €/bbl)	
		GJ/t	€ /t	€ /GJ	variability		€ /t	€ /GJ
Wheat grain	13%	14.8	95	6.4	16%	0.05	100	6.7
Sugar beet	77%	3.8	25	6.5	16%	0.05	26	6.8
Rapeseed	10%	23.8	237	9.9	14%	0.05	248	10.4
Sunflower seed	10%	23.8	265	11.1	14%	0.05	278	11.7
Wheat straw	16%	14.4	35	2.4	13%	0.05	37	2.5
Waste wood	0%	18.0	50	2.8	13%	0.05	53	2.9
Farmed wood	0%	18.0	77	4.3	5%	0.05	81	4.5
By-products substitutes								
Animal feed substitute		14.4	95	6.6	20%	0.10	105	7.3
Glycerine substitute		20.0	130	6.5	16%	0.68	218	

Why are the crop prices different from our last version?

- In Version 1 we used 2002 prices, when cereals price was high.
- Here in Version 2 we start off from a 2012 price projection from DG AGRI,
  based on FAPRI and OECD studies. They agree:
  - Oilseed prices will rise due to increased demand in China etc.
  - Cereals prices will increase slightly
- Our wheat price is now for new high-yield, low-protein, feed-wheat varieties costing 45 €/t less than hard-wheat commodity price.
- Animal feed by-product prices were calculated by cost-of-substituted-soybean cake: now we have direct market price projections.
- Farmed wood price was calculated indirectly from the wheat price. Now we have a market price with subsidies stripped out.
- Sugar beet cost shows strong geographic variation: we calculate the price at which it competes with wheat for making ethanol.

Cost of raw materials for conventional biofuels

- For a *marginal* increase in biofuels production, prices can be taken from (DG-AGRI / FAPRI) 2012 world price projections.
- But prices rise because of demand from expanding biofuels:
  - market flexibility estimated from historical trends + possible supply increase
- Price rise also depends on the size of the market; i.e. trading scenario:
  - With current trading agreements, world oilseed prices would rise in the order of 10% due to additional demand from 5.75% EU bio-diesel.
  - Maximum EU production would result in higher oil seed prices.
  - Little price increase for cereals if set-aside area is used.
- By-product prices fall drastically (e.g. 30%) with extra supply from biofuels production.
- Price of imported ethanol is assumed to equal that from the cheapest ethanol-from-wheat pathway in EU.

Example of production cost calculation

Ethanol from wheat grain

(oil at 25 €/bbl)

DDGS to		Animal feed				Energy			
Energy production scheme		Conv. Boiler	CCGT	Coal CHP	Straw CHP	CCGT	CCGT	Coal CHP	Straw CHP
Pathway code		WTET1a	WTET2a	WTET3a	WTET4a	WTET1b	WTET2b	WTET3b	WTET4b
Plant scale									
Ethanol	kt/a	100							
	PJ/a	2.7							
	MW	93							
	h/a	8000							
Wheat grain (13% moisture)	kt/a	338							
	PJ/a	5.0							
	€/t	*95+-16%*							
	M€/a	**32.1**							
Capex	*M€*	*60+-20%*	*78+-20%*	*105+-20%*	*105+-40%*	*60+-20%*	*78+-20%*	*105+-20%*	*105+-40%*
Capital charge @ 12%	**M€/a**	**7.2**	**9.4**	**12.6**	**12.6**	**7.2**	**9.4**	**12.6**	**12.6**
Opex	**M€/a**	**9.1**	**1.8**	**4.7**	**7.3**	**9.1**	**1.8**	**4.7**	**7.3**
Fixed		1.8	2.3	4.7	4.7	1.8	2.3	4.7	4.7
Net energy and chemicals		7.3	-0.5	0.0	2.6	7.3	-0.5	0.0	2.6
Credit for DDGS	kt/a	-114							
	€/t	*74*				*24*			
	M€/a	**-8.4**				**-2.7**			
Total annual production cost	**M€/a**	**39.9**	**34.8**	**41.0**	**43.5**	**45.6**	**40.5**	**46.7**	**49.2**
Total specific production cost	**€/GJ**	**14.9**	**13.0**	**15.3**	**16.2**	**17.0**	**15.1**	**17.4**	**18.4**
of which:									
Wheat grain		12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
Capex		2.7	3.5	4.7	4.7	2.7	3.5	4.7	4.7
Opex		3.4	0.7	1.8	2.7	3.4	0.7	1.8	2.7
Credits		-3.2	-3.2	-3.2	-3.2	-1.0	-1.0	-1.0	-1.0

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Example of distribution cost calculation

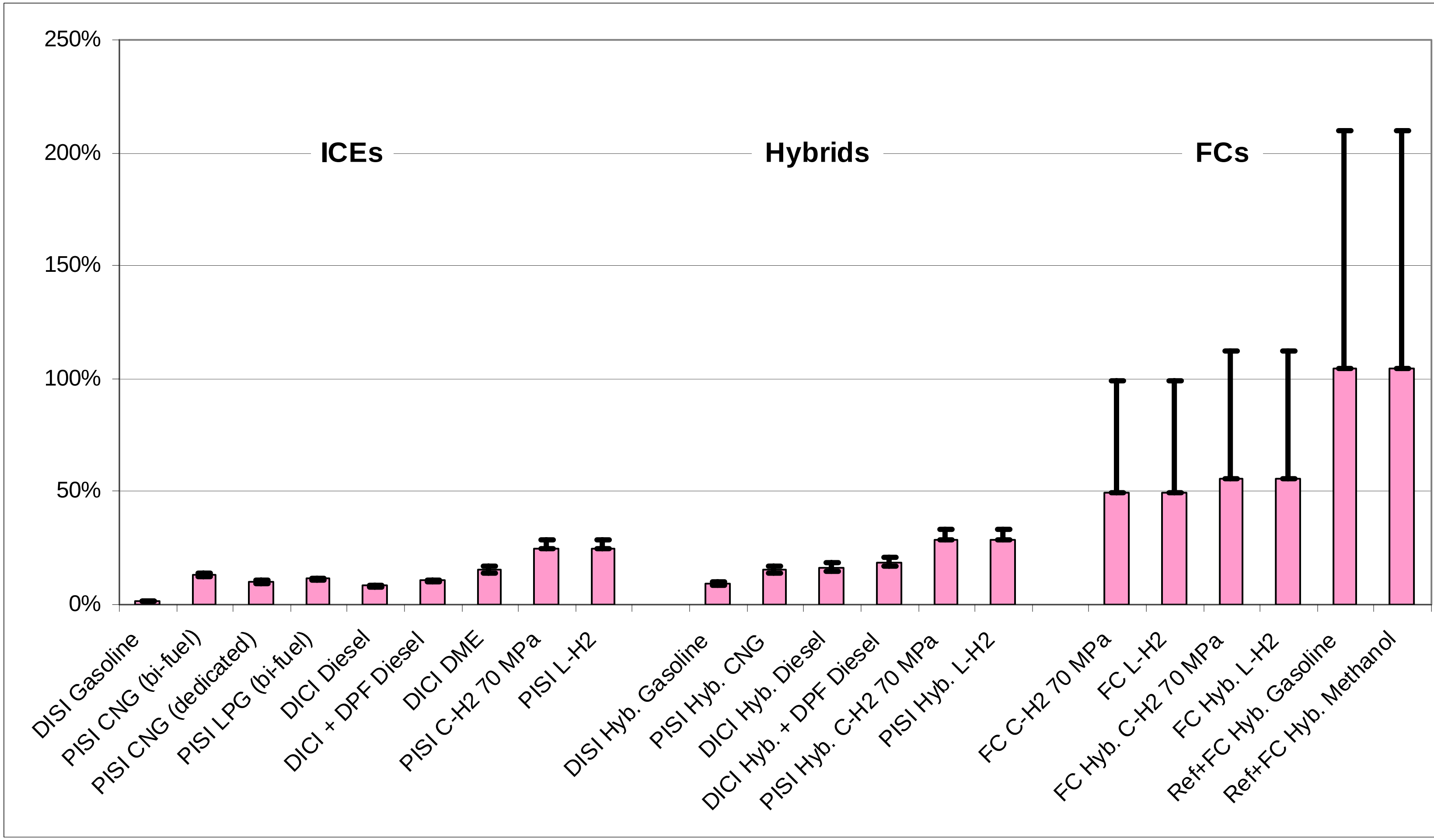
Liquid fuels

Fuel	*Energy consumption*			Energy cost	Distribution infrastructure[16]	Refuelling station		
	Diesel	*Electricity kWh/GJ*				Capex	Opex	Annual cost
	MJ/GJ	*MV*	*LV*	€/GJ	€/GJ	k€	k€/a	k€/a
Liquid fuels								
Conv. gasoline and diesel[1]					[2]			
Gasoline	*4.6*	*0.6*	*0.9*	0.1	0.2			
Diesel	*4.6*	*0.6*	*0.9*	0.1	0.2			
Ethanol[3]	*11.3*	*0.7*	*0.9*	0.2	0.6 [4]			
Bio-diesel[3]	*8.1*	*0.7*	*0.9*	0.1	0.5 [4]			
Syn-diesel					[4]			
Large scale or import[5]	*4.6*	*0.6*	*0.9*	0.1	0.2			
Small scale[6]	*6.9*	*0.2*	*0.9*	0.1	0.5			
Methanol					[4]	50	4	10
Large scale or import[7]	*12.7*	*0.7*	*0.9*	0.2	2.1			
Small scale[8]	*7.6*		*0.9*	0.1	0.6			
DME						125	10	25
Large scale import[7]	*11.5*	*0.5*	*0.9*	0.2	2.9 [9]			
Large scale EU[7]	*11.5*	*0.5*	*0.9*	0.2	1.8			
Small scale[8]	*6.9*		*0.9*	0.1	0.5			

(1) 250 km, barge/rail/pipeline + 150 km road, also includes ethers
(2) Notional cost for marginal tankage, railcars, trucks, etc
(3) 2 x 150 km, road
(4) Notional cost for additional tankage, railcars, trucks, etc
(5) 250 km, barge/rail/pipeline + 150 km road
(6) 2 x 150 km, road (e.g. small scale wood-based plant)
(7) 500 km, 50/50 rail/road
(8) 150 km, road (e.g. small scale wood-based plant)
(9) Including long-distance shipping

Additional cost of alternative 2010+ vehicles

Base: Gasoline PISI 2010+



Road fuels and vehicle market assumptions: substitution scenario

		Total	Gasoline	Diesel
Fuels market 2015[(1)]				
Total	Mt/a		93	204
	Mtoe/a	305	95	209
	PJ/a	12790	3996	8794
Fuel to passenger cars			100%	33%
	PJ/a	6928	3996	2932
Vehicle population				
Passenger car population[(1)]	M	247	156	91
Specific fuel consumption	GJ/car/a		25.7	32.1
Vehicle lifetime	Years		13	15
New vehicle sales	M/a	18.1	12.0	6.1
Energy and GHG of model vehicle		2010+ ICE		
		Average	PISI	CIDI/DPF
TTW energy	MJ/km	1.84	1.90	1.77
WTW energy	MJ/km	2.12	2.16	2.05
WTW GHG	g/km	161	164	156
Distance driven				
Per vehicle	km/a		13517	18157
Total	Tm/a	3763	2103	1659
Refuelling stations	k	100		
Substitution scenario		5% of distance driven		
		Total	Gasoline	Diesel
Distance driven	Tm/a	188	105	83
Conventional fuels substituted	PJ/a	346	200	147
Alternative vehicle sales	M/a	0.90	0.60	0.30
Required ref. stations coverage	k	20.0		
Base GHG emissions	Mt/a	30.3	17.3	13.0

(1) Source: [Wood MacKenzie 2005]

Total demand and gasoline/diesel ratio significantly changed from version 1

Car population figure reduced from version 1

These figures are for replacing like for like and may not be representative of an evolving car market

WTW savings and costs: detailed data

Fuel	*Powertrain*	Alt. fuel consumed	Fuel substituted		Base case	WTW savings[1,2]				Incremental cost over ref. scenario			Cost of substitution		Cost of CO_2 avoided
			Gasoline	Diesel	GHG	Energy (PJ/a)		GHG		G€ /a			€ /t fossil fuel	€ / 100 km	
Oil price @25 €/bbl		PJ/a	PJ/a		Mt CO_{2eq}/a	Total	Fossil	Mt CO_{2eq}/a	% of base	WTT	Vehicles	Total			€ /t CO_{2eq}
Gasoline															
Diesel															
Both fuels															
Conventional	Hybrids	291	200	145	30.1	62	**62**	**4.7**	**16%**	-0.3	1.6	1.2		0.65	**260**
CNG (pipeline 4000 km / LNG)			200	145	30.1										
	PISI (BF)	353				-36	-36	**4.3**	**14%**	0.7	1.7	2.4	302	1.29	**564**
	PISI (ded.)	351				-33	-33	**4.4**	**15%**	0.7	1.1	1.9	234	1.00	**422**
	Hybrid	261				76	**76**	**10.9**	**36%**	0.3	2.0	2.4	299	1.27	**219**
CBG (mixed sources)	PISI (BF)	353				-291	**376**	**50.4**	**167%**	4.9	1.7	6.6	824	3.51	**130**
LPG (remote)	PISI (BF)	356	356		30.1	-1	-1	**3.8**	**12%**	1.1	1.4	2.5	308	1.31	**655**
Ethanol	PISI	200	200		17.3										
Sugar beet															
Pulp to fodder						-343	**54**	**5.6**	**32%**	1.9		1.9	413	1.82	**342**
Pulp to heat						-231	**166**	**11.1**	**65%**	2.2		2.2	478	2.10	**198**
Ex wheat															
DDGS to animal feed															
Conv. Boiler						-328	**50**	**5.3**	**30%**	1.9		1.9	407	1.79	**358**
NG GT + CHP						-278	**98**	**7.8**	**45%**	1.5		1.5	325	1.43	**193**
Lignite CHP						-321	**55**	-1.4	-8%	2.0		2.0	425	1.87	
Straw CHP						-310	**172**	**12.1**	**70%**	2.2		2.2	466	2.05	**178**
DDGS to energy															
Conv. Boiler						-233	**140**	**7.0**	**40%**	2.3		2.3	499	2.20	**331**
NG CCGT						-184	**187**	**9.5**	**55%**	1.9		1.9	417	1.83	**203**
Lignite CHP						-226	**145**	**0.3**	**2%**	2.4		2.4	517	2.27	**7856**
Straw CHP						-216	**261**	**13.8**	**80%**	2.6		2.6	558	2.45	**186**
Ex straw						-236	**206**	**15.3**	**89%**	1.0		1.0	220	0.97	**67**
Ex wood						-361	**173**	**12.9**	**75%**	3.0		3.0	651	2.86	**233**
Bio-diesel	CIDI+DPF	145		145	12.8										
Glycerine as chemical															
RME						-143	**108**	**6.8**	**53%**	1.5		1.5	438	1.80	**217**
REE						-152	**115**	**7.8**	**61%**	1.5		1.5	442	1.81	**190**
SME						-110	**124**	**10.0**	**78%**	1.6		1.6	469	1.92	**157**
Glycerine as animal feed															
RME						-150	**101**	**6.0**	**47%**	1.5		1.5	436	1.79	**243**
REE						-159	**109**	**7.1**	**56%**	1.5		1.5	440	1.80	**208**
SME						-117	**117**	**9.3**	**72%**	1.6		1.6	467	1.91	**169**
Synthetic diesel fuels		145		145	12.8										
Syn-diesel ex NG (remote)	CIDI+DPF					-75	-75	-1.2	-9%	0.2		0.2	51	0.21	
Syn-diesel ex coal	CIDI+DPF					-118	-118	-16.3	-127%	0.6		0.6	170	0.70	
Syn-diesel ex wood	CIDI+DPF					-150	**159**	**11.7**	**91%**	2.8		2.8	824	3.38	**237**
Syn-diesel ex wood via BL	CIDI+DPF					-109	**163**	**12.3**	**96%**	1.2		1.2	355	1.46	**97**
DME ex NG (remote)	CIDI					-48	-48	**0.2**	**2%**	1.2	0.3	1.5	452	1.85	
DME ex coal	CIDI					-104	-104	-15.0	-117%	1.2	0.3	1.5	452	1.85	
DME ex wood	CIDI					-124	**160**	**11.8**	**92%**	2.2	0.3	2.5	750	3.07	**215**
DME wood via BL	CIDI					-51	**164**	**12.4**	**96%**	1.1	0.3	1.3	400	1.64	**109**

WTW savings and costs: detailed data (cont'd)

Fuel	*Powertrain*	Alt. fuel consumed	Fuel substituted		Base case	WTW savings[1,2]				Incremental cost over ref. scenario			Cost of substitution		Cost of CO_2 avoided
			Gasoline	Diesel	GHG	Energy		GHG		G€ /a			€ /t fossil fuel	€ / 100 km	
Oil price @ 25 €/bbl		PJ/a	PJ/a		Mt CO_{2eq}/a	Total	Fossil	Mt CO_{2eq}/a	% of base	WTT	Vehicles	Total			€ /t CO_{2eq}
Hydrogen from thermal processes			200	145	30.1										
Ex NG reforming[3]	ICE PISI	314				-232	-232	-6.2	-21%	5.7	3.7	9.4	1171	5.00	
	ICE hybrid	278				-154	-154	-1.7	-6%	5.1	4.4	9.5	1194	5.09	
	FC	176				44	**44**	**9.8**	**33%**	3.9	8.0	11.9	1495	6.38	**1219**
	FC hybrid	157				82	**82**	**12.0**	**40%**	3.6	9.1	12.7	1594	6.80	**1059**
Ex coal gasification[3]	ICE PISI	314				-422	-421	-29.4	-98%	6.9	3.7	10.6	1324	5.65	
	ICE hybrid	278				-329	-328	-22.7	-76%	6.2	4.4	10.6	1327	5.66	
	FC	176				-63	-62	-13.3	-44%	4.2	8.0	12.2	1528	6.52	
	FC hybrid	157				-12	-12	-8.6	-28%	3.8	9.1	12.9	1617	6.90	
Ex wood gasification[3]	ICE PISI	314				-288	**346**	**26.6**	**88%**	6.9	3.7	10.6	1324	5.65	**398**
	ICE hybrid	278				-198	**352**	**27.0**	**90%**	6.2	4.4	10.6	1332	5.68	**394**
	FC	314				-288	**346**	**26.6**	**88%**	6.9	3.7	10.6	1324	5.65	**398**
	FC hybrid	157				55	**371**	**28.4**	**94%**	3.9	9.1	13.1	1637	6.98	**460**
Hydrogen from electrolysis			200	145	30.1										
Electricity ex															
NG	ICE PISI	314				-644	-644	-31.4	-104%	9.0	3.7	12.7	1586	6.77	
	ICE hybrid	278				-514	-514	-23.7	-79%	8.1	4.4	12.5	1564	6.68	
	FC	176				-252	-252	-8.1	-27%	5.5	8.0	13.5	1692	7.22	
	FC hybrid	157				-181	-181	-3.9	-13%	5.0	9.1	14.1	1768	7.54	
Coal	ICE PISI	314				-974	-974	-108.4	-360%	8.6	3.7	12.3	1534	6.55	
	ICE hybrid	278				-796	-796	-90.5	-300%	7.7	4.4	12.1	1518	6.48	
	FC	176				-373	-373	-47.6	-158%	5.3	8.0	13.3	1663	7.10	
	FC hybrid	157				-288	-288	-39.0	-130%	4.8	9.1	13.9	1742	7.43	
Nuclear	ICE PISI	314				-945	-944	**26.8**	**89%**	11.5	3.7	15.1	1894	8.08	**564**
	ICE hybrid	278				-796	-795	**27.2**	**90%**	10.3	4.4	14.7	1837	7.84	**540**
	FC	176				-696	-695	**27.2**	**90%**	6.9	8.0	14.9	1865	7.96	**549**
	FC hybrid	157				-576	-576	**27.5**	**91%**	6.2	9.1	15.4	1921	8.20	**559**
Wind	ICE PISI	314				-24	**349**	**26.5**	**88%**	11.3	3.7	15.0	1877	8.01	**566**
	ICE hybrid	278				23	**355**	**26.9**	**89%**	10.2	4.4	14.6	1822	7.78	**541**
	FC	176				50	**357**	**26.9**	**89%**	6.8	8.0	14.8	1856	7.92	**551**
	FC hybrid	157				88	**362**	**27.3**	**91%**	6.2	9.1	15.3	1913	8.16	**561**
Indirect hydrogen	Ref + FC		200	145	30.1										
Gasoline		304				50	**50**	**3.8**	**13%**	-0.3	17.6	17.4	2172	9.27	**4551**
Naphtha						59	**59**	**5.1**	**17%**	-0.3	17.6	17.4	2172	9.27	**3434**
Diesel						44	**44**	**3.1**	**10%**	-0.3	17.6	17.4	2172	9.27	**5622**
Methanol ex NG		277													
Remote/import						-50	-50	**3.0**	**10%**	1.4	17.6	19.0	2373	10.13	**6336**
4000 km NG						-71	-71	**1.3**	**4%**	1.4	17.6	19.0	2373	10.13	**14475**
Methanol ex coal						-139	-139	-25.5	-85%	1.4	17.6	19.0	2373	10.13	
Methanol ex wood						-177	-177	**26.9**	**89%**	2.2	17.6	19.8	2577	10.59	**737**
Methanol ex wood via BL						-44	-44	**28.1**	**93%**	0.9	17.6	18.5	2495	9.90	**659**

(1) i.e. a negative number denotes an increase

(2) Relative to the "business-as-usual" scenario: gasoline PISI for ethanol, diesel CIDI for diesel fuels and combined scenario for other fuels

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WTW savings and costs: detailed data (cont'd)

Fuel	*Powertrain*	Alt. fuel consumed	Fuel substituted		Base case	WTW savings[1,2]				Incremental cost over ref. scenario			Cost of substitution		Cost of CO_2 avoided
			Gasoline	Diesel	GHG	Energy (PJ/a)		GHG		G€ /a			€ /t fossil fuel	€ / 100 km	
Oil price @50 €/bbl		PJ/a	PJ/a		Mt CO_{2eq}/a	Total	Fossil	Mt CO_{2eq}/a	% of base	WTT	Vehicles	Total			€ /t CO_{2eq}
Gasoline															
Diesel															
Both fuels															
Conventional	Hybrids	291	200	145	30.1	62	**62**	**4.7**	**16%**	-0.7	1.6	0.9		0.48	**191**
CNG (pipeline 4000 km / LNG)			200	145	30.1										
	PISI (BF)	353				-36	-36	**4.3**	**14%**	0.2	1.7	1.8	229	0.98	**428**
	PISI (ded.)	351				-33	-33	**4.4**	**15%**	0.1	1.1	1.3	161	0.69	**290**
	Hybrid	261				76	**76**	**10.9**	**36%**	-0.6	2.0	1.5	182	0.78	**134**
CBG (mixed sources)	PISI (BF)	353				-291	**376**	**50.4**	**167%**	3.5	1.7	5.2	646	2.76	**102**
LPG (remote)	PISI (BF)	356	356		30.1	-1	-1	**3.8**	**12%**	1.1	1.4	2.5	313	1.34	**666**
Ethanol	PISI	200	200		17.3										
Sugar beet															
Pulp to fodder						-343	**54**	**5.6**	**32%**	1.2		1.2	250	1.10	**207**
Pulp to heat						-231	**166**	**11.1**	**65%**	1.1		1.1	234	1.03	**97**
Ex wheat															
DDGS to animal feed															
Conv. Boiler						-328	**50**	**5.3**	**30%**	1.3		1.3	272	1.19	**239**
NG GT + CHP						-278	**98**	**7.8**	**45%**	0.8		0.8	182	0.80	**108**
Lignite CHP						-321	**55**	-1.4	-8%	1.1		1.1	234	1.03	
Straw CHP						-310	**172**	**12.1**	**70%**	1.2		1.2	253	1.11	**97**
DDGS to energy															
Conv. Boiler						-233	**140**	**7.0**	**40%**	1.6		1.6	349	1.53	**231**
NG CCGT						-184	**187**	**9.5**	**55%**	1.2		1.2	259	1.14	**126**
Lignite CHP						-226	**145**	**0.3**	**2%**	1.4		1.4	311	1.37	**4734**
Straw CHP						-216	**261**	**13.8**	**80%**	1.5		1.5	330	1.45	**110**
Ex straw						-236	**206**	**15.3**	**89%**	-0.2		-0.2	-44	-0.20	**-13**
Ex wood						-361	**173**	**12.9**	**75%**	2.1		2.1	445	1.96	**160**
Bio-diesel	CIDI+DPF	145		145	12.8										
Glycerine as chemical															
RME						-143	**108**	**6.8**	**53%**	0.8		0.8	241	0.99	**119**
REE						-152	**115**	**7.8**	**61%**	0.8		0.8	246	1.01	**106**
SME						-110	**124**	**10.0**	**78%**	0.9		0.9	273	1.12	**92**
Glycerine as animal feed															
RME						-150	**101**	**6.0**	**47%**	0.8		0.8	229	0.94	**127**
REE						-159	**109**	**7.1**	**56%**	0.8		0.8	234	0.96	**110**
SME						-117	**117**	**9.3**	**72%**	0.9		0.9	260	1.07	**94**
Synthetic diesel fuels		145		145	12.8										
Syn-diesel ex NG (remote)	CIDI+DPF					-75	-75	-1.2	-9%	0.3		0.3	102	0.42	
Syn-diesel ex coal	CIDI+DPF					-118	-118	-16.3	-127%	0.1		0.1	20	0.08	
Syn-diesel ex wood	CIDI+DPF					-150	**159**	**11.7**	**91%**	2.2		2.2	654	2.68	**188**
Syn-diesel ex wood via BL	CIDI+DPF					-109	**163**	**12.3**	**96%**	0.6		0.6	187	0.77	**51**
DME ex NG (remote)	CIDI					-48	-48	**0.2**	**2%**	1.0	0.3	1.3	382	1.56	
DME ex coal	CIDI					-104	-104	-15.0	-117%	1.0	0.3	1.3	382	1.56	
DME ex wood	CIDI					-124	**160**	**11.8**	**92%**	1.6	0.3	1.9	568	2.33	**163**
DME wood via BL	CIDI					-51	**164**	**12.4**	**96%**	0.8	0.3	1.1	325	1.33	**88**

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WTW savings and costs: detailed data (cont'd)

Fuel	Powertrain	Alt. fuel consumed	Fuel substituted		Base case	WTW savings[1,2]				Incremental cost over ref. scenario			Cost of substitution		Cost of CO_2 avoided
			Gasoline	Diesel	GHG	Energy (PJ/a)		GHG		G€ /a			€ /t fossil fuel	€ / 100 km	
Oil price @50 €/bbl		PJ/a	PJ/a		Mt CO_{2eq}/a	Total	Fossil	Mt CO_{2eq}/a	% of base	WTT	Vehicles	Total			€ /t CO_{2eq}
Hydrogen from thermal processes			200	145	30.1										
Ex NG reforming[3]	ICE PISI	314				-232	-232	-6.2	-21%	5.9	3.7	9.6	1197	5.11	
	ICE hybrid	278				-154	-154	-1.7	-6%	5.1	4.4	9.5	1191	5.08	
	FC	176				44	**44**	**9.8**	**33%**	3.3	8.0	11.3	1417	6.05	**1156**
	FC hybrid	157				82	**82**	**12.0**	**40%**	2.9	9.1	12.0	1501	6.40	**997**
Ex coal gasification[3]	ICE PISI	314				-422	-421	-29.4	-98%	6.3	3.7	10.0	1251	5.34	
	ICE hybrid	278				-329	-328	-22.7	-76%	5.5	4.4	9.9	1237	5.28	
	FC	176				-63	-62	-13.3	-44%	3.1	8.0	11.1	1389	5.93	
	FC hybrid	157				-12	-12	-8.6	-28%	2.6	9.1	11.7	1469	6.27	
Ex wood gasification[3]	ICE PISI	314				-288	**346**	**26.6**	**88%**	5.7	3.7	9.4	1173	5.01	**352**
	ICE hybrid	278				-198	**352**	**27.0**	**90%**	5.0	4.4	9.4	1173	5.01	**347**
	FC	176				12	**368**	**28.2**	**94%**	2.9	8.0	10.9	1364	5.82	**387**
	FC hybrid	157				55	**371**	**28.4**	**94%**	2.5	9.1	11.6	1452	6.19	**408**
Hydrogen from electrolysis			200	145	30.1										
Electricity ex															
NG	ICE PISI	314				-644	-644	-31.4	-104%	9.6	3.7	13.3	1663	7.10	
	ICE hybrid	278				-514	-514	-23.7	-79%	8.4	4.4	12.9	1608	6.86	
	FC	176				-252	-252	-8.1	-27%	5.1	8.0	13.1	1640	7.00	
	FC hybrid	157				-181	-181	-3.9	-13%	4.4	9.1	13.6	1697	7.24	
Coal	ICE PISI	314				-974	-974	-108.4	-360%	7.7	3.7	11.4	1423	6.07	
	ICE hybrid	278				-796	-796	-90.5	-300%	6.7	4.4	11.1	1395	5.95	
	FC	176				-373	-373	-47.6	-158%	4.0	8.0	12.0	1505	6.42	
	FC hybrid	157				-288	-288	-39.0	-130%	3.5	9.1	12.6	1577	6.73	
Nuclear	ICE PISI	314				-945	-944	**26.8**	**89%**	10.4	3.7	14.1	1767	7.54	**526**
	ICE hybrid	278				-796	-795	**27.2**	**90%**	9.2	4.4	13.6	1700	7.25	**499**
	FC	176				-696	-695	**27.2**	**90%**	5.5	8.0	13.6	1698	7.24	**499**
	FC hybrid	157				-576	-576	**27.5**	**91%**	4.8	9.1	14.0	1749	7.46	**508**
Wind	ICE PISI	314				-24	**349**	**26.5**	**88%**	10.2	3.7	13.9	1741	7.43	**525**
	ICE hybrid	278				23	**355**	**26.9**	**89%**	9.0	4.4	13.4	1677	7.16	**498**
	FC	176				50	**357**	**26.9**	**89%**	5.4	8.0	13.5	1683	7.18	**500**
	FC hybrid	157				88	**362**	**27.3**	**91%**	4.7	9.1	13.9	1736	7.41	**508**
Indirect hydrogen	Ref + FC		200	145	30.1										
Gasoline		304				50	**50**	**3.8**	**13%**	-0.5	17.6	17.1	2142	9.14	**4487**
Naphtha						59	**59**	**5.1**	**17%**	-0.5	17.6	17.1	2142	9.14	**3386**
Diesel						44	**44**	**3.1**	**10%**	-0.5	17.6	17.1	2142	9.14	**5543**
Methanol ex NG		277													
Remote/import						-50	-50	**3.0**	**10%**	0.5	17.6	18.1	2262	9.65	**6039**
4000 km NG						-71	-71	**1.3**	**4%**	0.6	17.6	18.2	2283	9.74	**13922**
Methanol ex coal						-139	-139	-25.5	-85%	0.5	17.6	18.1	2262	9.65	
Methanol ex wood						-177	-177	**26.9**	**89%**	1.6	17.6	19.2	2369	10.27	**714**
Methanol ex wood via BL						-44	-44	**28.1**	**93%**	0.0	17.6	17.6	2284	9.40	**626**

(1) i.e. a negative number denotes an increase

(2) Relative to the "business-as-usual" scenario: gasoline PISI for ethanol, diesel CIDI for diesel fuels and combined scenario for other fuels

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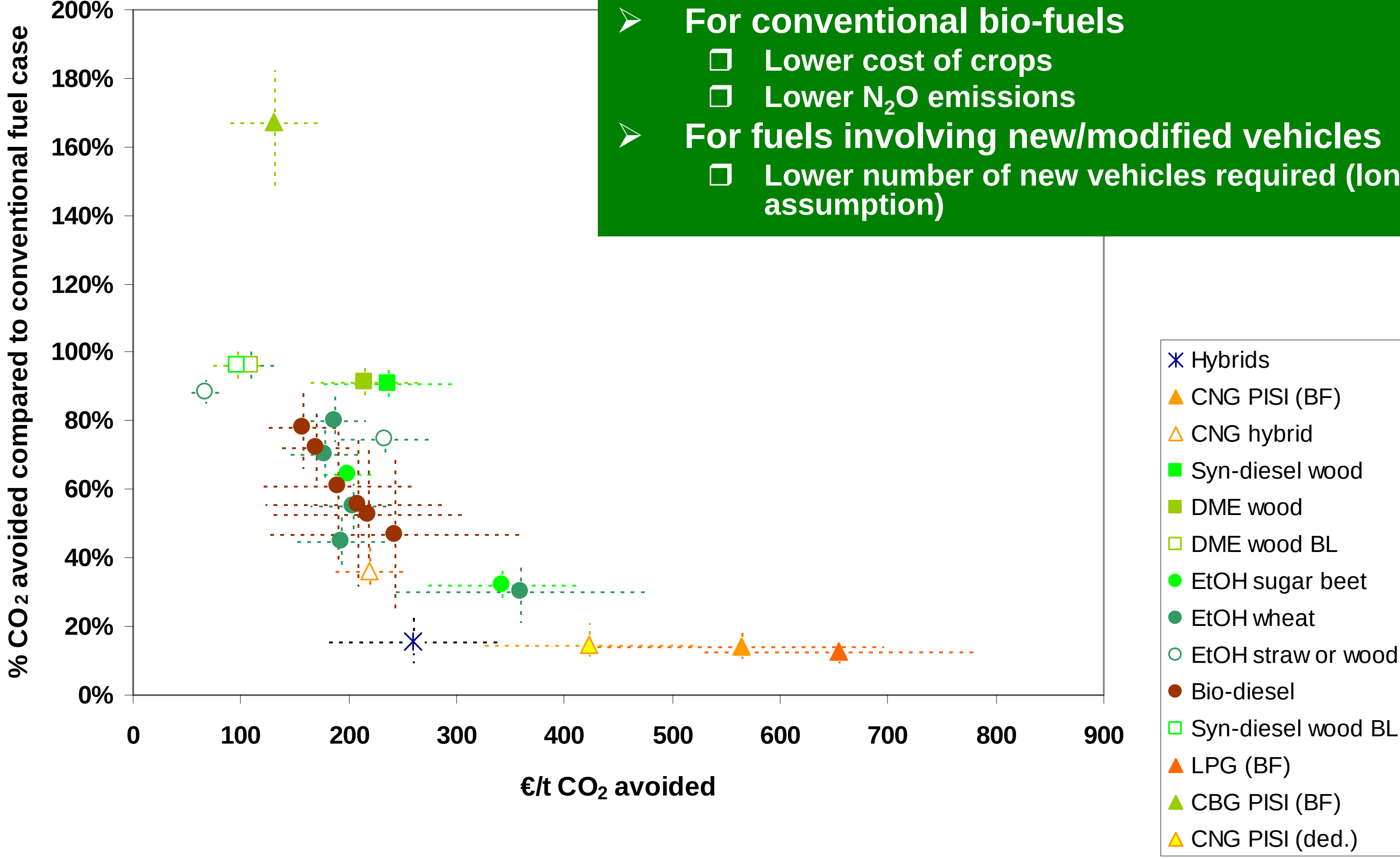
Cost vs potential for CO_2 avoidance

Oil price scenario: 25 €/bbl

Liquid fuels, DME/LPG/CNG/CBG



- **€/t CO_2 figures are generally lower than in version 1. Main reasons are**
- **For conventional bio-fuels**
  - **Lower cost of crops**
  - **Lower N_2O emissions**
- **For fuels involving new/modified vehicles**
  - **Lower number of new vehicles required (longer life assumption)**

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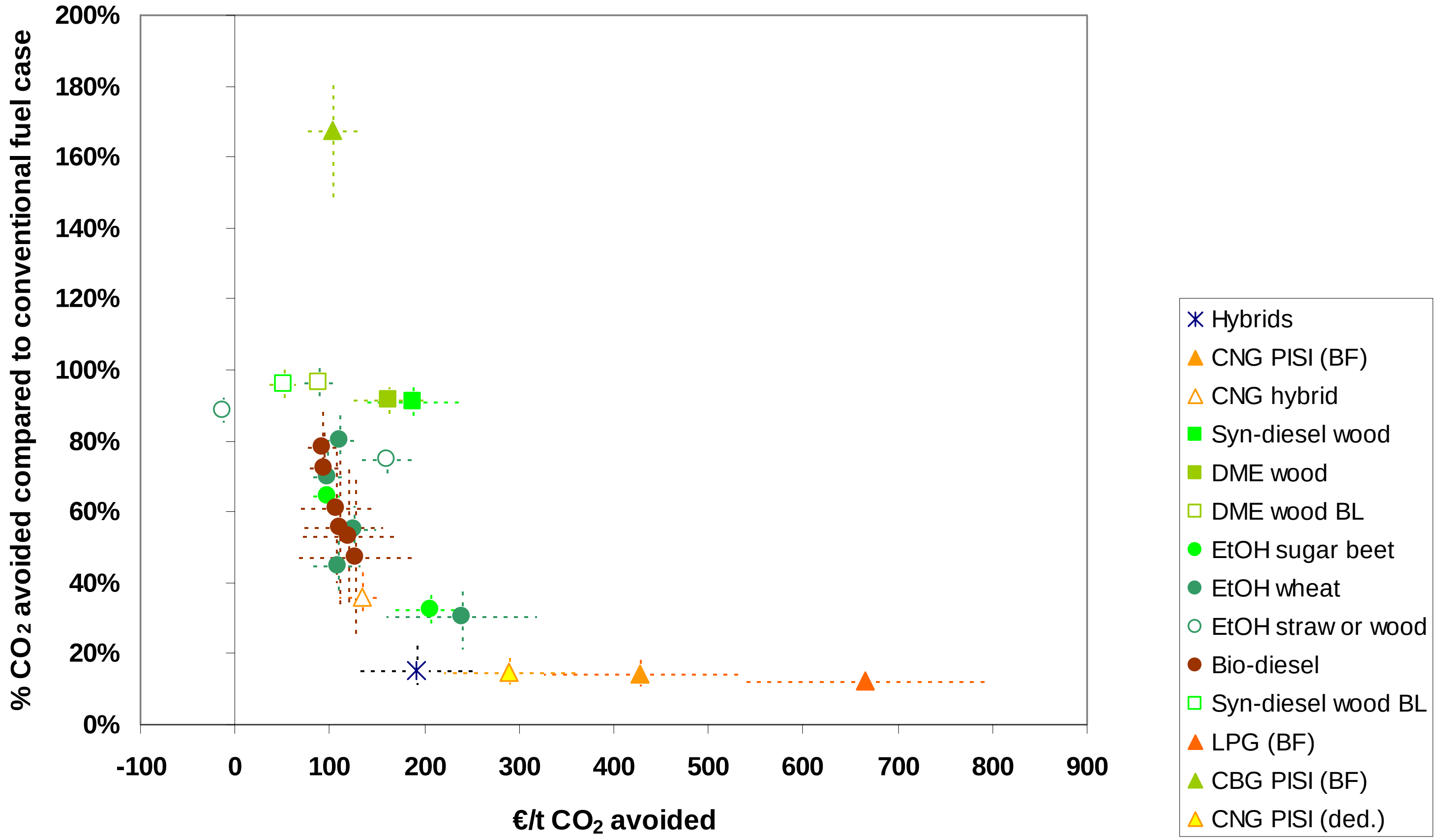
Cost vs potential for CO_2 avoidance

Oil price scenario: 50 €/bbl

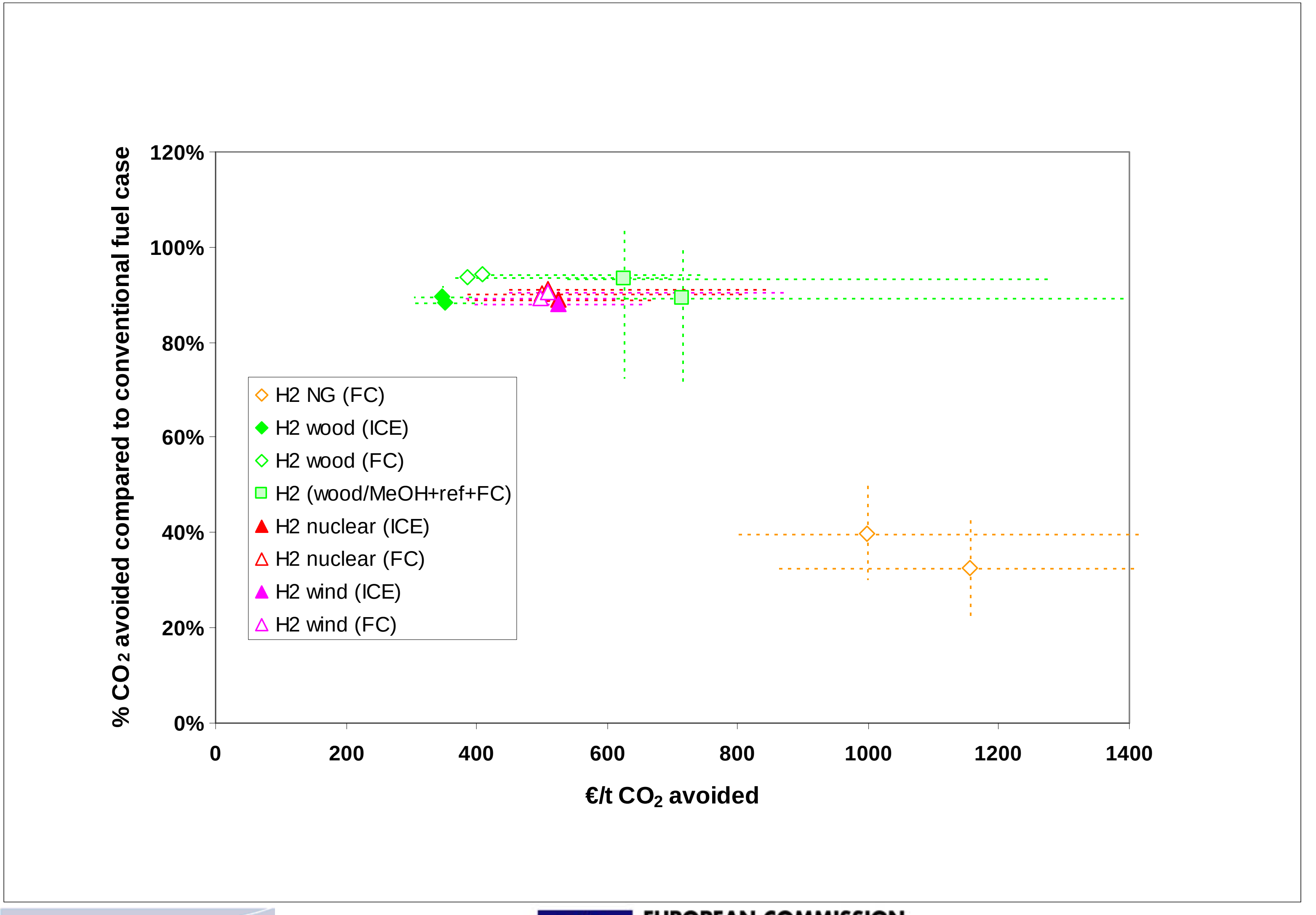
Liquid fuels, DME/LPG/CNG/CBG



Cost vs potential for CO_2 avoidance

Oil price scenario: 50 €/bbl

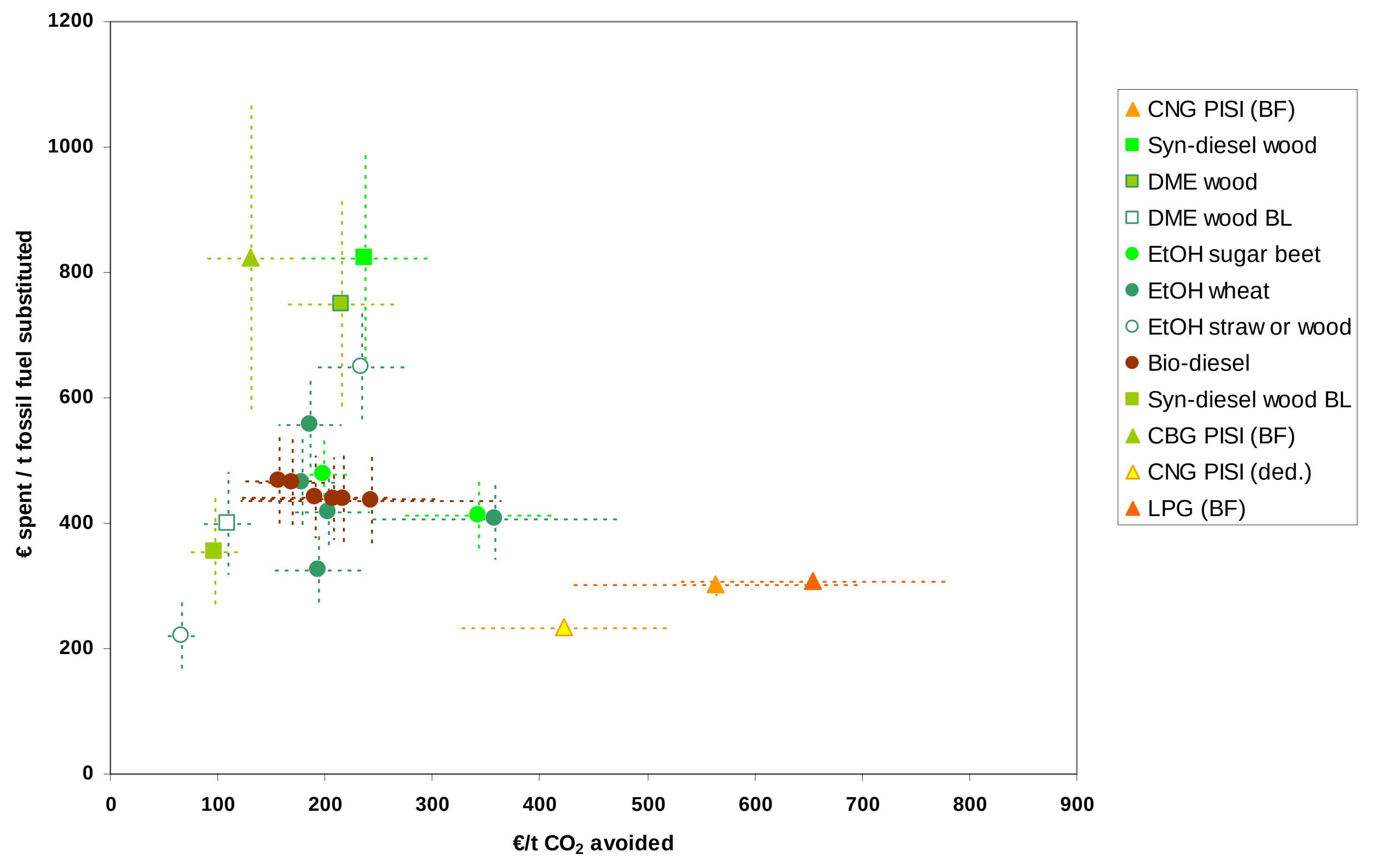
Hydrogen



Cost of CO_2 avoidance vs cost of substitution

Oil price scenario: 25 €/bbl

Liquid fuels, DME/LPG/CNG/CBG



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Cost of CO_2 avoidance vs cost of substitution

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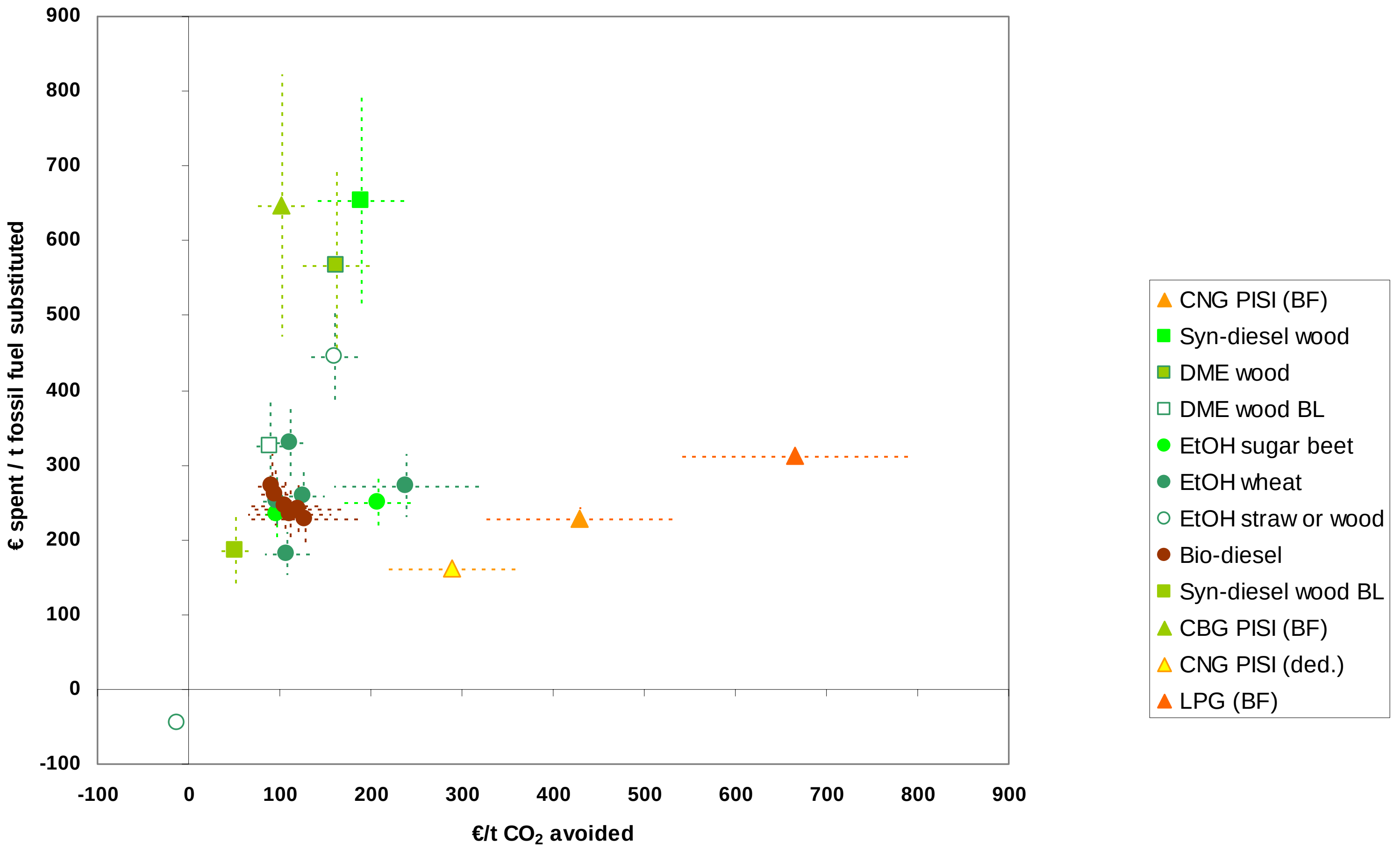
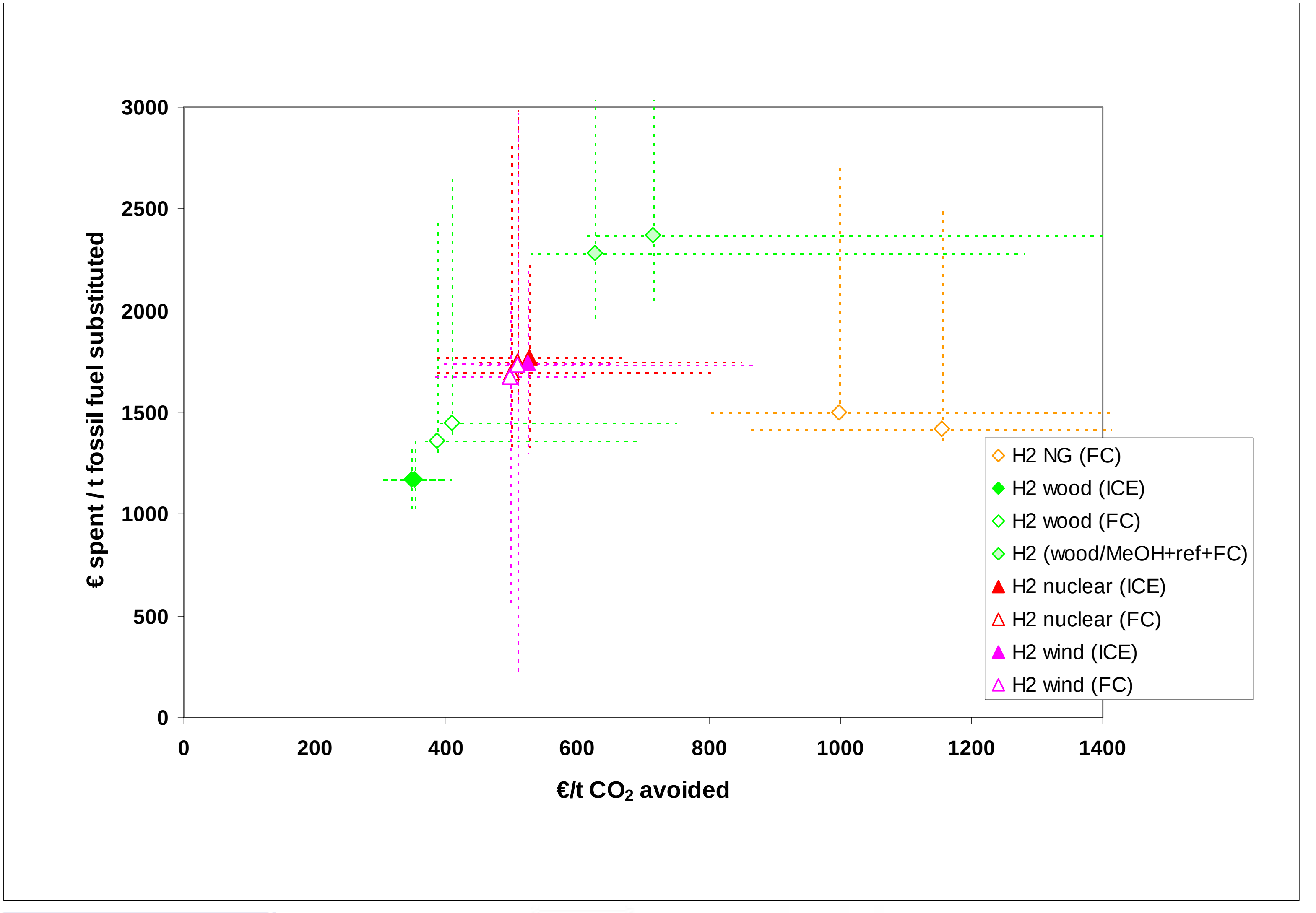


Cost of CO_2 avoidance vs cost of substitution

Oil price scenario: 50 €/bbl

Hydrogen



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Cost of substitution vs CO_2 avoidance

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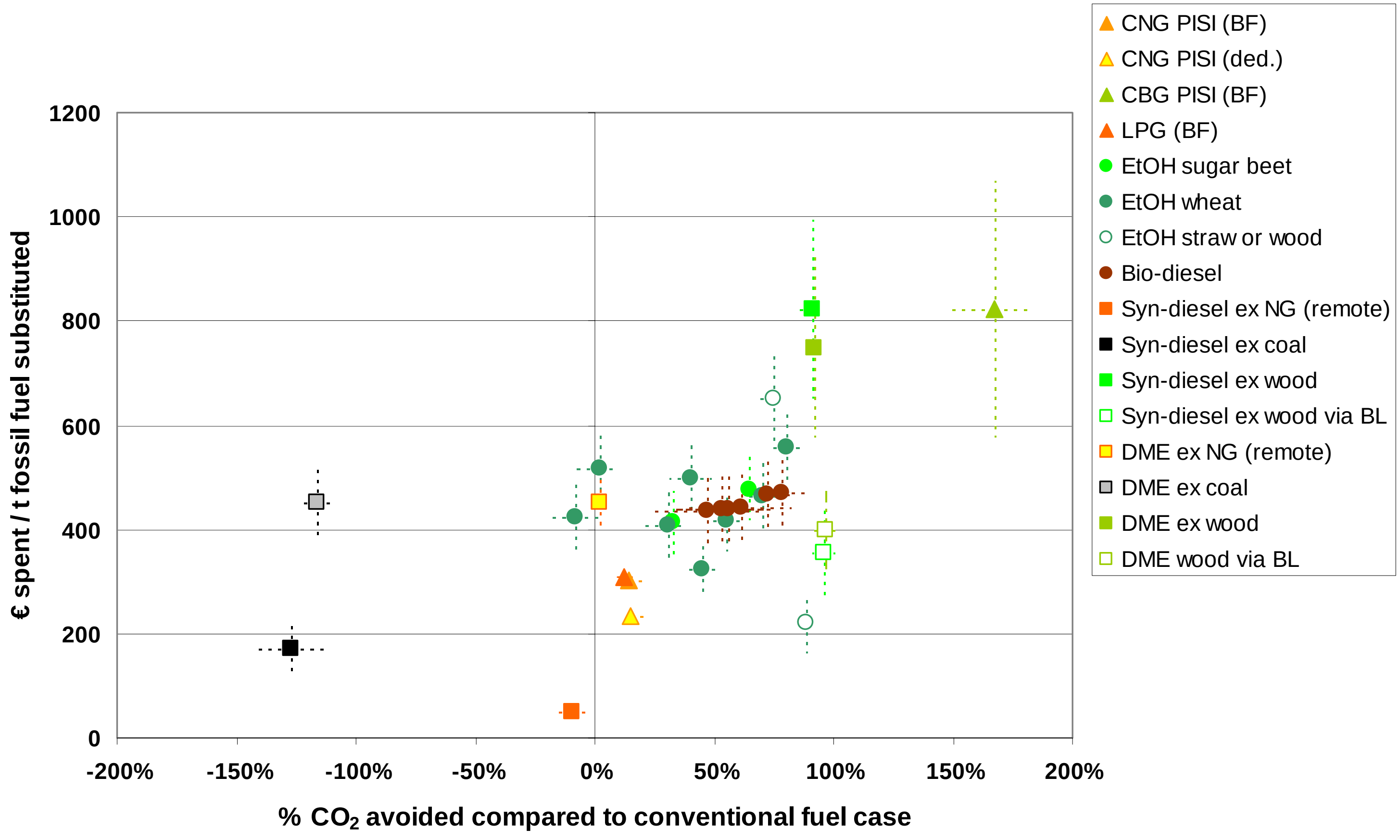

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Cost of substitution vs CO_2 avoidance

Oil price scenario: 50 €/bbl

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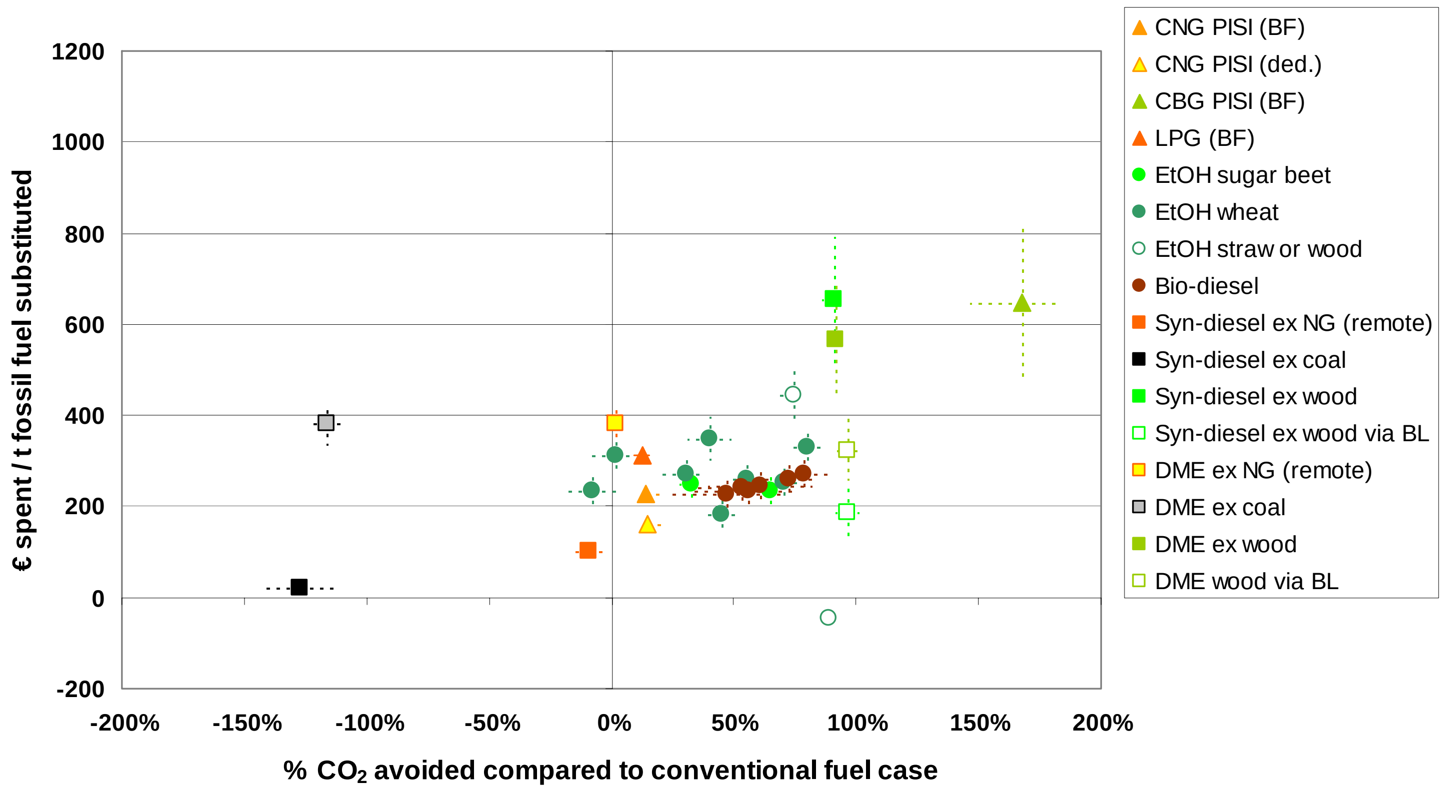

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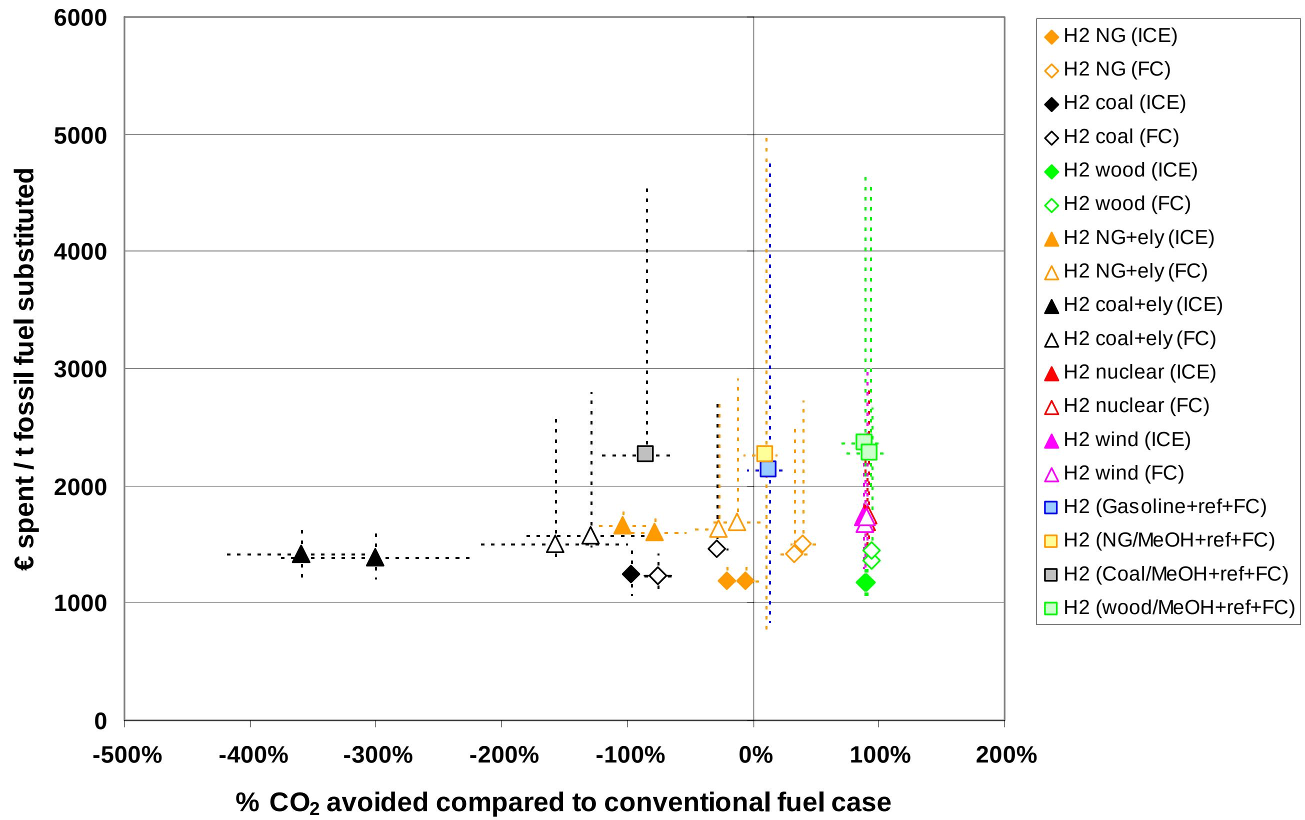
Cost of substitution vs CO_2 avoidance

Oil price scenario: 50 €/bbl

Hydrogen



General Observations: Costs

- A shift to renewable / low carbon sources is currently costly
  - However, high cost does not always result in high GHG emission reductions
  - At comparable costs GHG savings can vary considerably
- The cost of CO_2 avoidance using conventional biofuels is around
  - 150-300 €/ton CO_2 when oil is at 25 €/bbl
  - 100-200 €/ton CO_2 when oil is at 50 €/bbl
- Syn-diesel, DME and ethanol from wood have the potential to save substantially more GHG emissions than current bio-fuel options at comparable or lower cost per tonne of CO_2 avoided.
  - Issues such as land and biomass resources, material collection, plant size, efficiency and costs, may limit the application of these processes
- Syn-diesel from natural gas (GTL) is near CO_2 neutral compared to conventional diesel but can potentially provide a cost-effective alternative

General Observations: Costs

- For CNG, the cost of CO_2 avoided is relatively high as CNG requires specific vehicles and a dedicated distribution and refuelling infrastructure
- The technical challenges in distribution, storage and use of hydrogen lead to high costs.
  - The cost, availability, complexity and customer acceptance of vehicle technology utilizing hydrogen should not be underestimated

Conventional bio-fuels: imports or EU-produced?

- Target: 5.75% of conventional fuels on energy content basis

PJ/a	2015 demand	5.75% (2010 target)	8.00% (2020 target)
Gasoline	3996	230	320
Diesel	8794	506	704

- 5.75% of diesel to bio-diesel and gasoline to ethanol
- EU can produce cereals competitively
- Putting the CAP set-aside rate to 0% would produce almost enough extra cereals to achieve 5.75% gasoline substitution with bio-ethanol with no cereals price increase. But bio-diesel production would be far less.
- 5.75% Bio-diesel target = 14% of foreseen world oilseed production 2012
  = 192% of 2005 EU oilseed production
  - EU already imports half its total oilseed requirements
  - With present trading agreements most oilseeds would be imported: about 10% price increase
  - Much larger price increases if there is *sudden* expansion of biofuels.

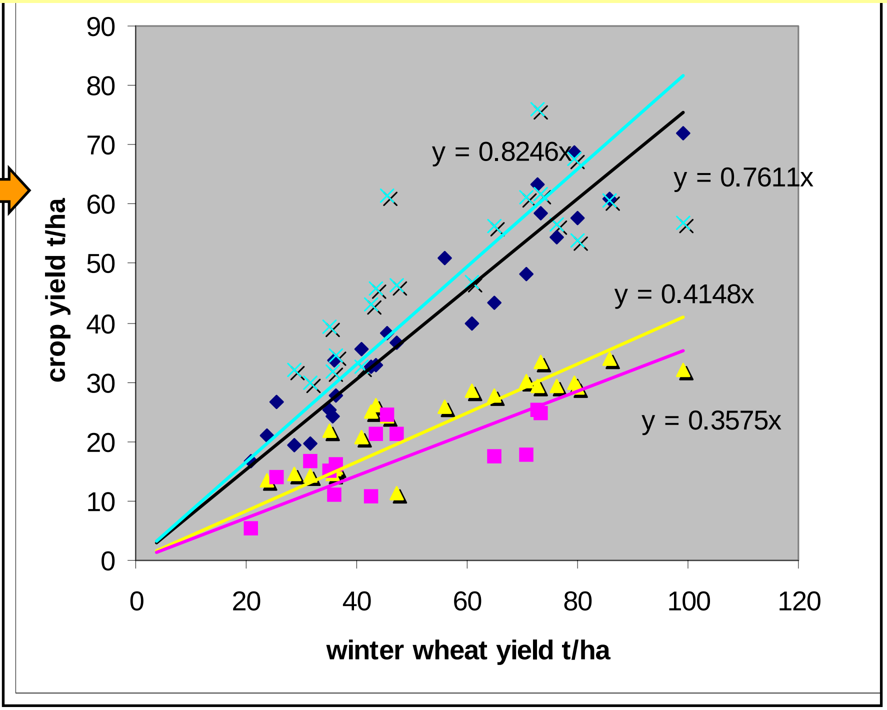
Scenario in table

- If barriers prevent import of more oilseeds:
  - Target of 5.75% bio-diesel not reachable
  - Huge price rises
- Bio-ethanol imports
  - Would allow faster market introduction of bio-ethanol without large price rises
  - Import bill repaid by continued EU grain exports

Potential for EU-production of biofuels: methodology

- We cannot increase arable area without a large release of soil carbon,
  - ❒ negates the benefit of biofuels for decades
- So we only use existing arable land + set-asides (not much soil carbon accumulated there)
- Yields vary enormously, but yields of different crops are roughly proportional to cereals yield on same land
  - ❒ So we calculate the cereals potential and then relate this to other crops by yield ratios
- Total cereals potential available for energy=
  cereals on set-aside (lower yield)
  + cereals on ex-sugar beet land (new sugar policy)
  + yield improvement

EU-25 yields of different crops vs. wheat yield



- Max. EU biofuels scenario: internal market means half the extra cereals potential is used for oilseeds instead
  - ❒ The conversion factor is the yield ratio adjusted for the “break crop effect”
  - ❒ e.g. 1 tonne rapeseed replaces 1.6 tonnes cereals

Potential of wood farming: comparison with VIEWLS

- We estimate a maximum of 1855 PJ of farmed wood could be grown in EU-25 in 2010-2015, at 77 €/tonne, on the spare cereals area (according to DG-AGRI forecast) and set-asides.

- VIEWLS project estimates cost and availability of farmed wood in CEEC-10 countries 2030
- For similar economic scenario to ours, (also constant-food): 8000 PJ wood at 62 €/tonne
- VIEWLS finds the maximum possible potential,
  - re-assigning the use of all non-urban land to its optimum agricultural use, according to their model
  - land not needed for food (or wood-industry) according to their model is assigned to energy crops
  - That means planting on grazing and forest land (the animals are fed on crops).
- Ploughing up grazing land (or forest) for arable crops is known to be very bad for soil carbon stocks. Therefore we excluded it: VIEWLS do not.
  - The soil-carbon effects of planting short-rotation forestry (SRF) on grazing land or natural forest land are not known: they could be almost as bad as arable crops, or negligible compared to the benefit from growing biofuels.
  - So we are being conservative by not considering wood farming on grazing land, whilst VIEWLS are being optimistic by considering it for any energy crop.
- VIEWLS assume large yield improvements by 2030

Potential of biomass residues

- Availability of biomass for *biofuels* is less than for *bio-energy*:
  - Advanced biofuels plants need to be large for reasonable economics
  - Crop residues are mostly highly dispersed: better suited to local heating
- STRAW is the largest and most concentrated residue
  - After subtracting existing use, net 820 PJ straw
  - But <230 PJ available for biofuels conversion plants (>120 MJ_{th})
- FOREST RESIDUALS + net growth of commercial forest
  - Technically available 1000 PJ = forest residuals (20% with stumps) + 25% spare growth
  - At pulp mills: 325 PJ, of which Black-liquor-to-fuel may be **244 PJ** (rest electricity)
    ...for a cost of 2.8 €/GJ
  - Rest is more dispersed: assume 1/3 available to large plants for biofuels: **228 PJ**
    ...available at the price of farmed wood (4.1 €/GJ)
  - but practically all wood-industry waste (e.g. sawdust) already used
- *COMPRESSED* BIOGAS
  - Purification and compression only economic on *large plant*
  - These need slurry from 8000 cows or 50,000 pigs within10-20 km
    AND 20% organic waste ...for reasonable economics
  - Together these limit *compressed* biogas to around 200 PJ/a
  - More biogas may be produced in smaller, simpler plant for local heat and power

Potential of conventional bio-fuels

- Targets 5.75% of conventional fuels on energy content basis

PJ/a	2015 demand	5.75% (2010 target)	8.00% (2020 target)
Gasoline	3996	230	320
Diesel	8794	506	704

- Availability: no change in food production

	Crop		Ethanol	Bio-diesel	Fossil fuels replaced		WTW avoidance				Cost @25 €/bbl			Cost @50 €/bbl		
							WTW Fossil energy		WTW CO_{2eq}		€/ t conv fuel	G€/a	€/ t CO2 av	€/ t conv fuel	G€/a	€/ t CO2 av
	Mt/a	PJ/a	PJ/a	PJ/a	PJ/a	Mt/a	MJ/MJ	PJ/a	g/MJ	Mt/a						
Surplus sugar beet	10.0	38	20			0.5	0.27	5	28.4	0.6	413	0.19	342	250	0.12	207
Surplus expressed as wheat grain																
From set-asides	31.0															
From net land released by sugar reform	7.6															
From improved yields	16.9															
Total surplus	55.6															
To ethanol	26.4	390	209			4.8	0.46	97	36.4	7.6	359	1.74	243	216	1.05	148
To oil seeds	*29.2*															
Equivalent oil seeds(1)	⇩															
Rape	13.0	310		181		4.2	0.72	130	45.1	8.2	437	1.84	230	235	0.99	123
Sunflower	3.5	83		52		1.2	0.83	43	67.4	3.5	467	0.57	169	260	0.32	94
Existing oil seeds for energy																
Rape	5.6	133		78		1.8	0.72	56	45.1	3.5	437	0.79	230	235	0.42	123
Total			**230**	**311**	**541**	**12.5**		**333**		**23.4**	**409**	**5.13**	228	**231**	**2.89**	129
Gasoline/diesel market coverage			**5.75%**	**3.5%**												
Total road fuel market coverage			**4.2%**													
WTW avoidance, % of fossil fuels base case								**2.3%**		**2.1%**						

(1) Assumes 80/20 rape/sunflower

Availability scenarios for advanced bio-fuels

Resource	Mt/a	PJ/a	Ethanol PJ/a	Syn-diesel PJ/a	*(Naphtha)* PJ/a	DME PJ/a	Hydrogen PJ/a
Surplus sugar beet	10.0	38.4	20				
Wheat straw	15.9	230	97				
Surplus wheat grain							
Set-asides	*31.0*						
From net land released by sugar reform	*7.6*						
Improved yields	*16.9*						
	⇩		←		Or		→
As farmed wood	87.3	1571	539	491	*164*	802	980
Existing oil seeds for energy	*5.6*						
	⇩						
As farmed wood	15.8	284	97	89	*30*	145	177
Waste wood	26.2	471	162	167	*56*	274	332
Biogas		200					

Assumptions for all scenarios:

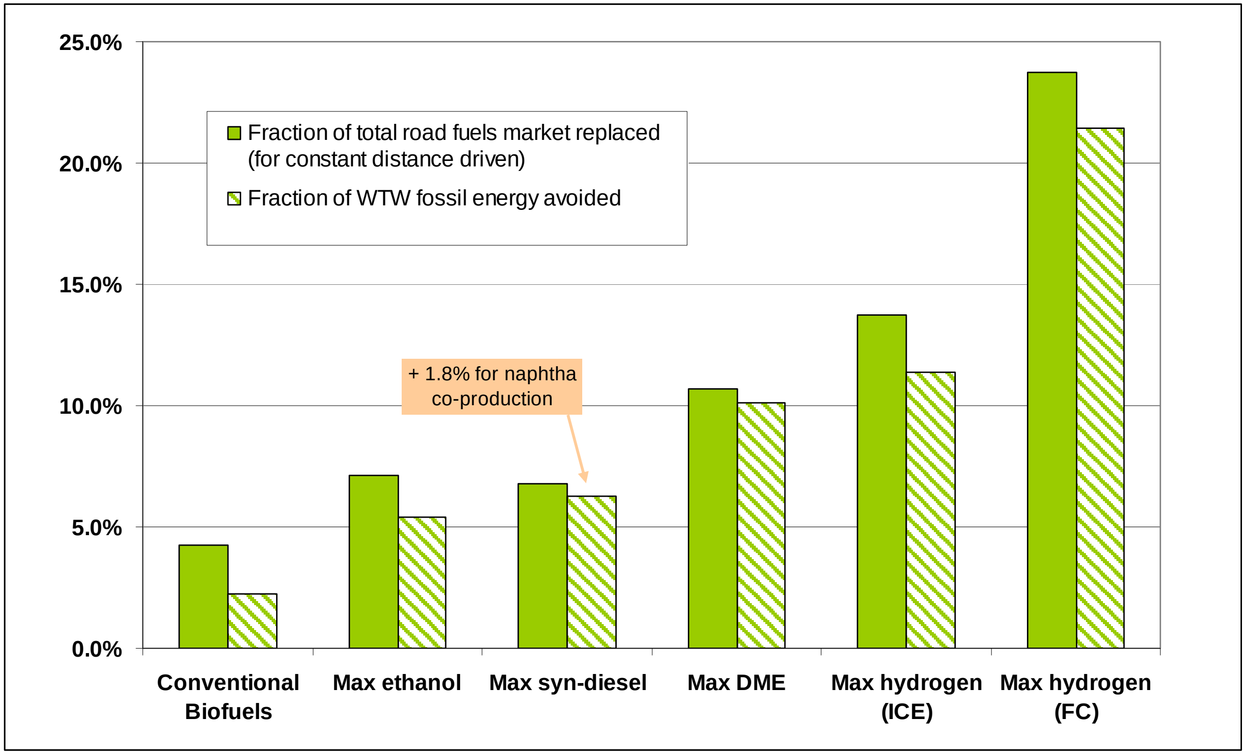
- Marginal sugar beet still grown
- Straw only used for ethanol production
- 50% of waste wood used though black liquor route

Availability scenarios for advanced bio-fuels

Scenario	Total Alt fuels	Road fuels market coverage			Fossil fuels replaced		WTW avoidance						Cost					
							WTW fossil energy			WTW CO_{2eq}			Oil @ 25 €/bbl			Oil @ 50 €/bbl		
	PJ/a	Gasoline	Diesel	Total	PJ/a	Mt/a	MJ/MJ	PJ/a	% of total for fossil fuels	g/MJ	Mt/a	% of total for fossil fuels	€/ t fossil fuel	G€/a	€/ t CO_2 av	€/ t fossil fuel	G€/a	€/ t CO_2 av
"Max ethanol" total	**915**			**7.2%**	**915**	**21.2**	**0.87**	**796**	**5.4%**	**65**	**60**	**5.3%**	**600**	**12.7**	**219**	**389**	**8.2**	**143**
Ethanol	915	22.9%																
"Max syn-diesel" total	**864**	**2.9%**	**8.5%**	**6.8%**	**864**	**20.0**	**1.07**	**926**	**6.3%**	**79**	**68**	**6.1%**	**709**	**14.2**	**210**	**530**	**10.6**	**156**
Ethanol	117	2.9%			117	2.7		105	0.7%		8	0.7%						
Syn-diesel	747		8.5%		747	17.3		820	5.6%		60	5.4%						
Naphtha	*249*							*261*	*1.8%*		*21*	*1.9%*						
"Max DME" total	**1338**	**2.9%**	**14.3%**	**10.7%**	**1370**	**31.8**	**1.11**	**1489**	**10.1%**	**82**	**110**	**9.8%**	**679**	**21.6**	**198**	**503**	**16.0**	**146**
Ethanol	117	2.9%			117	2.7		105	0.7%		8	0.7%						
DME	1221		14.3%		1253	29.1		1384	9.4%		102	9.1%						
"Max hydrogen" total	**1606**																	
Ethanol	117	2.9%		0.9%	117	2.7		105	0.7%		8	0.7%						
Hyd used in ICE		**26.7%**	**7.8%**	**13.7%**	**1753**	**40.6**	**1.04**	**1675**	**11.4%**	**82**	**131**	**11.7%**	**1170**	**47.5**	**366**	**990**	**40.2**	**309**
Hydrogen	1489	23.7%	7.8%	12.8%	1636	37.9		1570	10.7%		123	10.9%						
Hyd used in FC		**45.2%**	**14.0%**	**23.7%**	**3034**	**70.3**	**1.97**	**3158**	**21.4%**	**151**	**243**	**21.6%**	**1487**	**104.5**	**430**	**1294**	**90.9**	**374**
Hydrogen	1489	42.3%	14.0%	22.8%	2917	67.6		3053	20.7%		235	20.9%						
Biogas	**200**	**2.8%**	**0.9%**	**1.5%**	**196**	**4.5**	**0.99**	**198**	**1.3%**	**140**	**28**	**2.5%**	**824**	**3.7**	**130**	**646**	**2.9**	**102**

- With the biomass resources realistically available within the EU, advanced liquid bio-fuels could replace 20-30 Mt/a of fossil fuels and save 60-110 Mt/a of GHG emissions
  - Cost per t of fossil fuel substituted tend to be higher than for conventional bio-fuel but the cost per t of CO_2 avoided are of the same order of magnitude
- The substitution scope is higher for hydrogen, particularly when used in fuel cells
  - Costs are higher than for liquid fuels
- In addition Biogas used as CBG could replace 4.5 Mt/a of fossil fuels and save 28 Mt/a of GHG

The potential of biomass in Europe: overview



2012 projections including:

- Set-asides
- Sugar beet surplus
- Agricultural yield improvements
- Wheat straw surplus
- Unused wood waste
- Organic waste to biogas

But excluding

- Currently not cultivated land
- Pastures

Conventional Biofuels:	Wheat and sugar beet to ethanol, oilseeds to bio-diesel, wheat straw not used
All other scenarios:	*Surplus sugar beet and wheat straw to ethanol* *Organic waste to biogas*
Max ethanol:	Woody biomass from all available land to ethanol
Max syn-diesel:	Woody biomass from all available land to syn-diesel *Also produces naphtha*
Max DME:	Woody biomass from all available land to DME
Max Hydrogen:	Woody biomass from all available land to hydrogen (used in a fuel cell vehicle)

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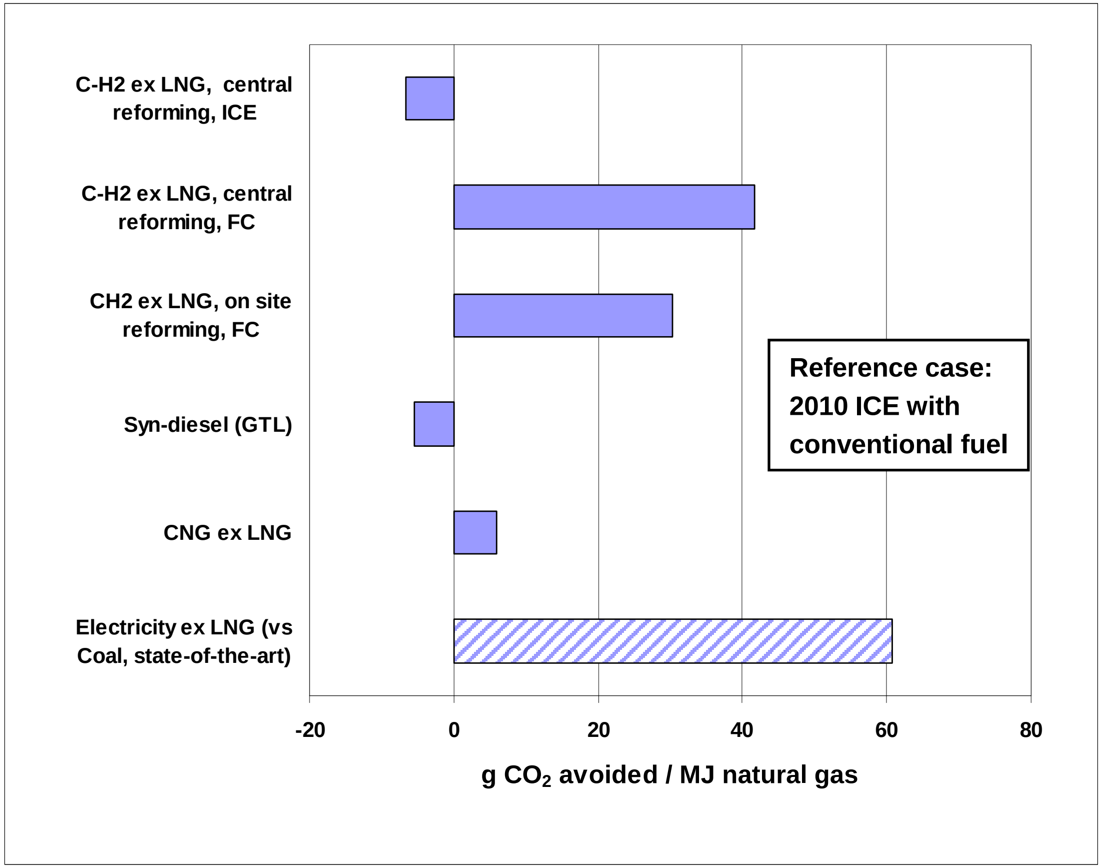
There are many ways of using gas

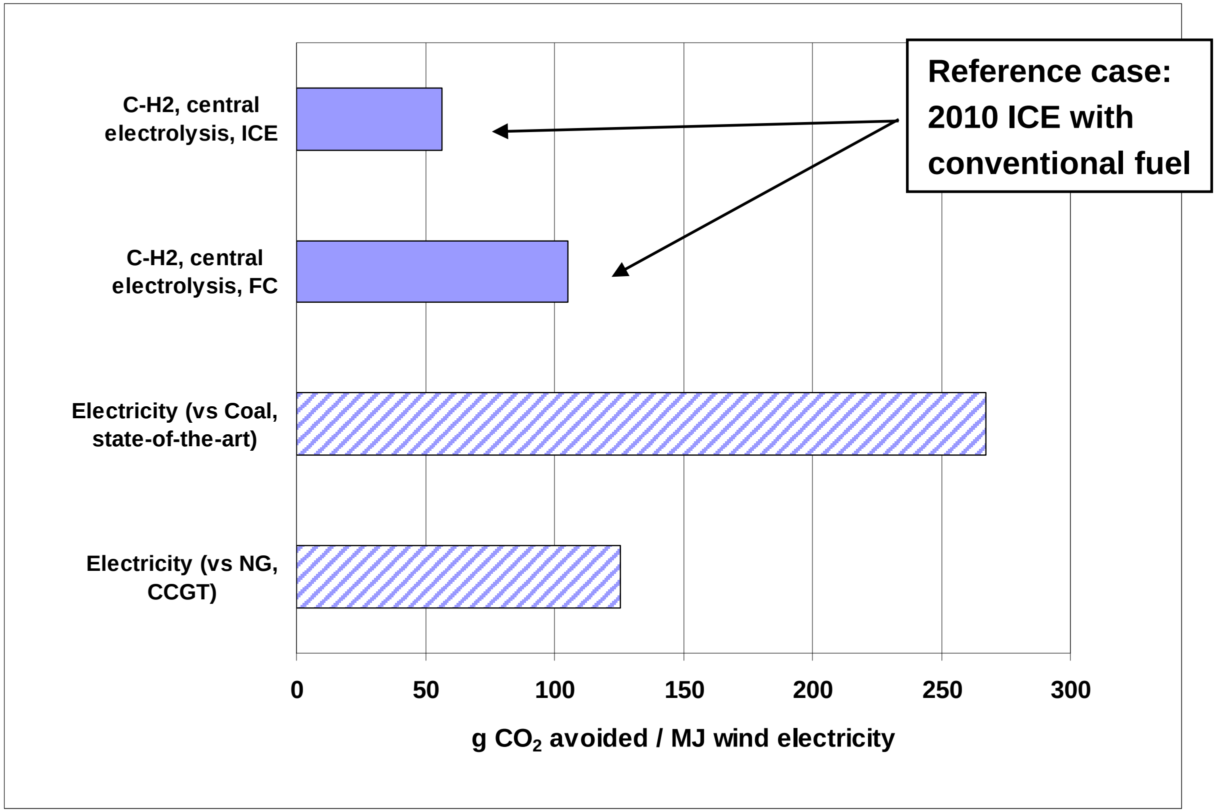
Potential for CO_2 avoidance from 1 MJ remote gas (as LNG)



Substitution of marginal electricity is likely to be the most CO_2 efficient
Only fuel cell vehicles can come close

There are many ways of using wind power

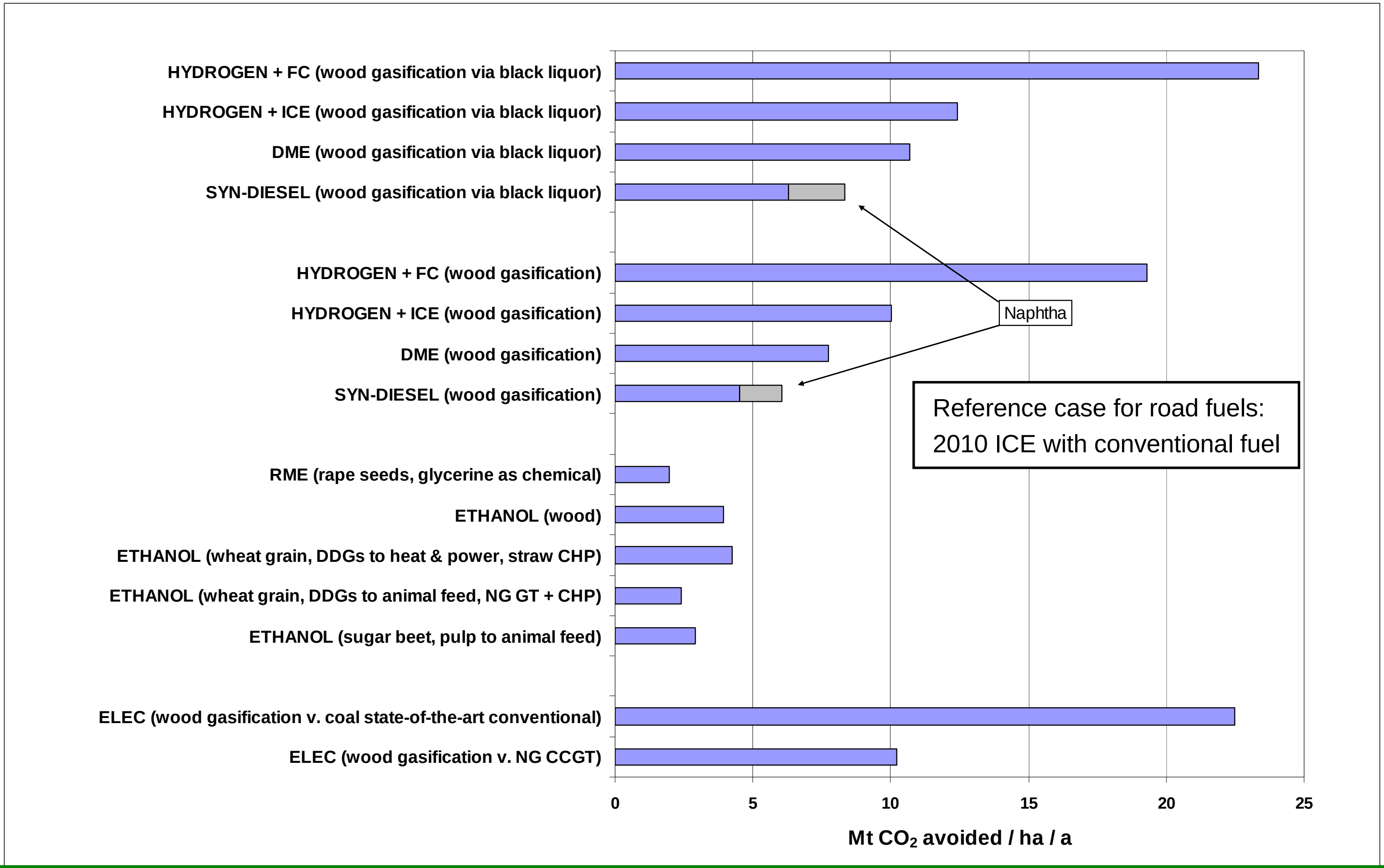
Potential for CO_2 avoidance from 1 MJ wind electricity



- Substitution of marginal electricity is likely to be the most CO_2 efficient
- Only fuel cell vehicles can come close
- Issues related to energy storage must also be taken into account

Alternative use of primary energy resources - Biomass

Potential for CO_2 avoidance from 1 ha of land



Wood gasification or direct use of biomass for heat and power offers greatest GHG savings

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Conclusions

- A shift to renewable/low fossil carbon routes may offer a significant GHG reduction potential but generally requires more energy. The specific pathway is critical
- No single fuel pathway offers a short term route to high volumes of "low carbon" fuel.
  - Contributions from a number of technologies/routes will be needed.
  - A wider variety of fuels may be expected in the market
  - Blends with conventional fuels and niche applications should be considered if they can produce significant GHG reductions at reasonable cost
- Transport applications may not maximize the GHG reduction potential of renewable energies
- Optimum use of renewable energy sources such as biomass and wind requires consideration of the overall energy demand including stationary applications
  - More efficient use of renewables may be achieved through direct use as electricity rather than road fuels applications

Well-to-Wheels analysis of future automotive fuels and powertrains in the European context

The study report will be available on the WEB:

http://ies.jrc.cec.eu.int/WTW

For questions / inquiries / requests / notes

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